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PROPELLER TESTS IN THE LARGE SONIC WIND TUNNEL OF MODANE-AVRIEUX

Alain Masson

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16. Abstract

The installation designed by ONERA for investigations on full-scale or large-scale models of conventional aircraft or convertiplane propellers in the large sonic wind tunnel at the Modane-Avrieux Test Center is described. Some examples of tests carried out and typical results obtained illustrate the use capability of the equipment, which is also suitable for helicopter rotor tests.

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I. INTRODUCTION

The prediction of the performance and economy of an aircraft /3* depends on knowing as accurately as possible the performance of the propeller selected for the aircraft project.

There are two complementary methods available to the designer for establishing this: calculation (the Hamilton-Standard method in the USA, Hirsch method, programmed for the SNIAS in France, etc.), as well as wind tunnel tests.

These tests can only be carried out in large installations, capable of high velocities. Only these installations can simulate the Reynolds numbers [1] and the Mach numbers. This requirement led the Technical Aeronautical Service at the ONERA in 1962 to build a propeller test facility [2] designed for the large sonic wind tunnel S1 at Modane-Avrieux (Figure 1).

The recent appearance of VTOL and STOL projects in both France and in foreign countries utilized propeller propulsion or propeller supported lift, which has led to a number of tests on convertible propellers at Modane. During these tests, the ONERA with the permission of the Aeronautical Technical Service perfected the installation. It has been used very extensively since it was built. Also, an incidence system has been built which greatly enlarges its capacity, and it becomes possible to test propellers and helicopter rotors at high incidence [3].

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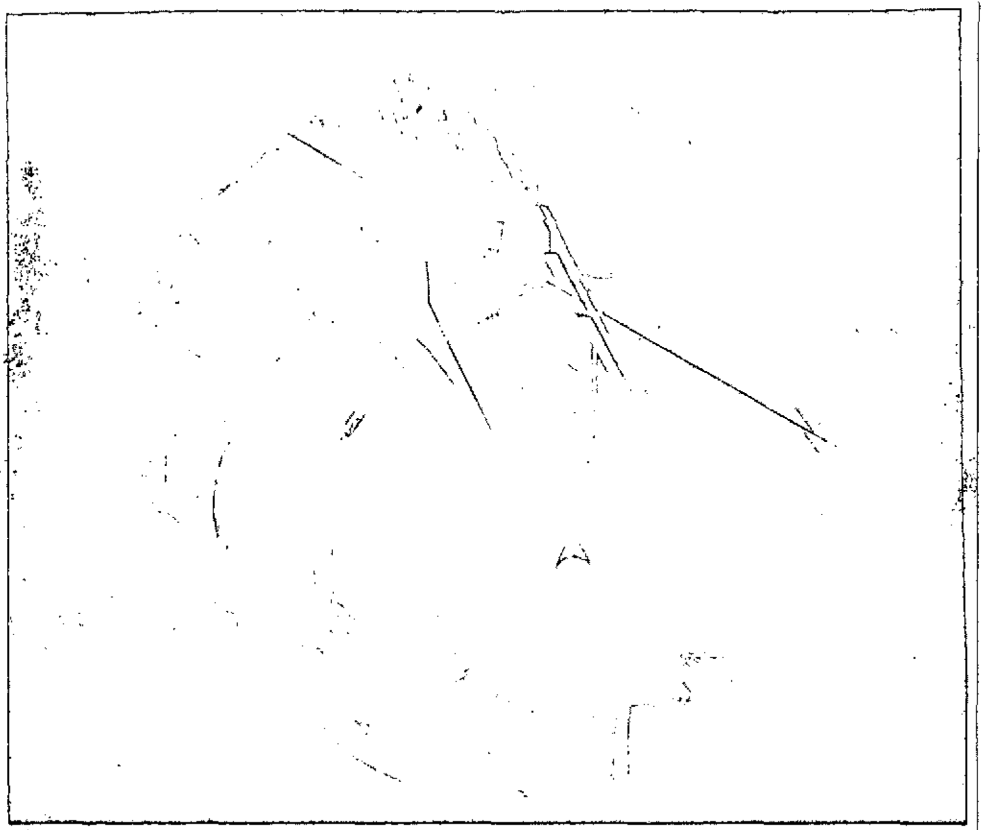


Figure 1. Model at a scale of 13/55 with a diameter of 4 meters in the test section No. 3 of the SIMA wind tunnel.

This document gives a general description of the propeller and convertible rotor test facilities, built by the engineers at the Modane-Avrieux center.

II. GENERAL REMARKS ON METHODS AND TEST FACILITIES /4

The calculation method can be used to select the geometry which is best adapted to any propeller with sufficient accuracy, which is adapted to certain particular operating modes. But these methods are not as sufficient for predicting the influence of secondary effects on global performance: compressibility, increased incidence of the propeller axis, and the environment around the propeller.

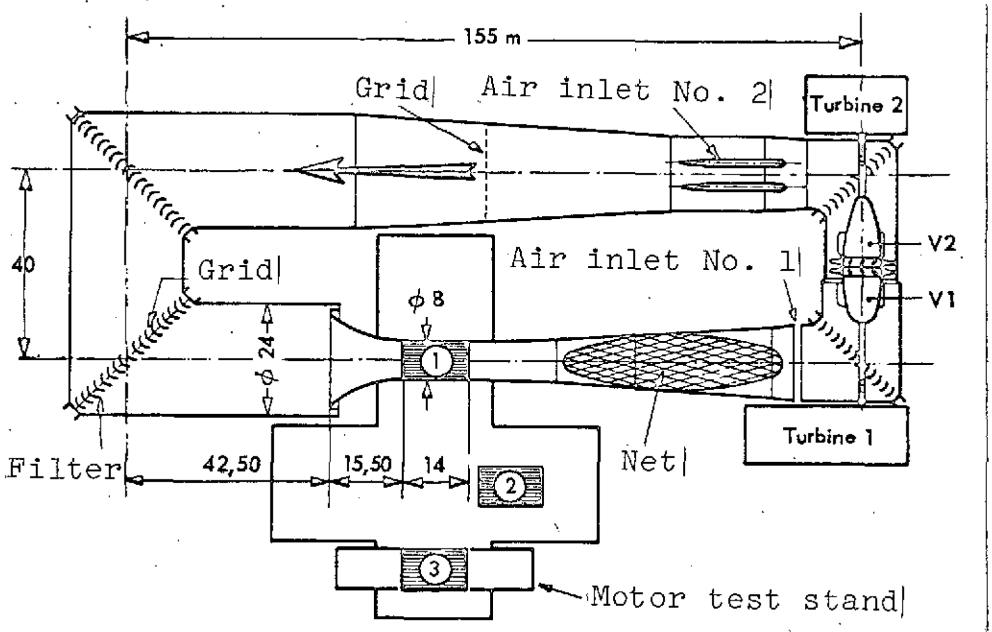


Figure 2. General description of SIMA wind tunnel.

The existing installation in the S1MA is designed to meet the needs and lead to a better understanding of phenomena, and is designed to improve the calculation methods.

II.1. Description of the Entire Installation

The propeller test installation in various configurations utilizes the wind tunnel S1 at the ONERA center installed at Modane-Avrieux.

This wind tunnel (Figure 2) has a velocity range between 10 m/sec and a velocity slightly above sonic velocity (Mach 1.02) in a cylindrical test section 8 meters in diameter and 14 meters long [4].

Three wagons (1, 2, and 3) make it possible to alternately introduce three test sections in the aerodynamic circuit (Figure

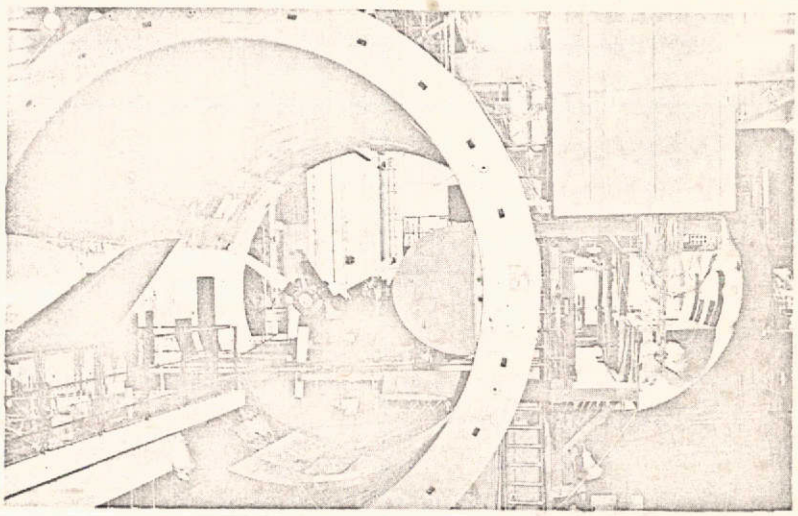


Figure 3. Wagon 3 which has part of a propeller mounted on it. Wagon 1 in the background.

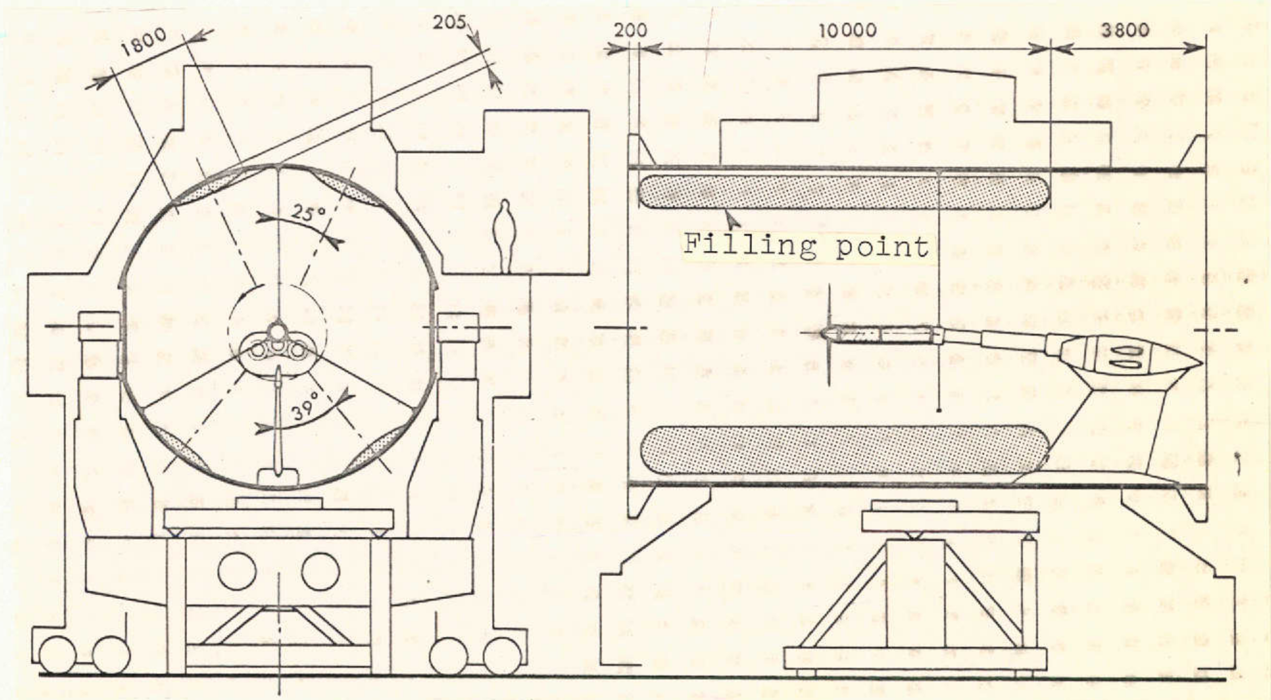


Figure 4. Lateral filling arrangement in test section No. 3 with the propeller test stand in the "minimum cylindrical body" configuration.

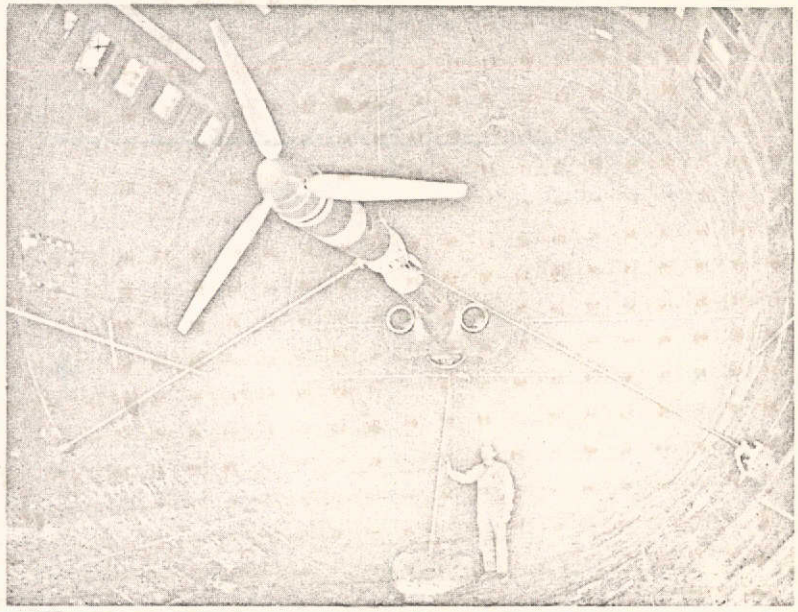


Figure 5. Propeller model with a diameter of 2.5 meters at a scale of 1/1.8 in wagon No. 2.

3). Only wagons 2 and 3 are utilized for propeller tests. Wagon 3 has two lateral filling points (Figure 4) designed to compensate for the obstruction produced in the test section for the propeller test stand in the "minimum cylindrical body" configuration. In particular, it is used for high velocity propeller tests (up to Mach 0.77). The wagon 2 is designed for convertible propeller tests at large incidence angles and at smaller velocities (up to Mach 0.35). However, it can also be utilized for tests in the "minimum cylindrical body" configuration (Figure 5).

The area command posts (wind tunnel and propeller) and measurement stands are distributed close to the test section (Figure 6) inside the building in which the various wagons move. The coarse measurement results are automatically transcribed onto punched tape or magnetic tape and are processed by the /6

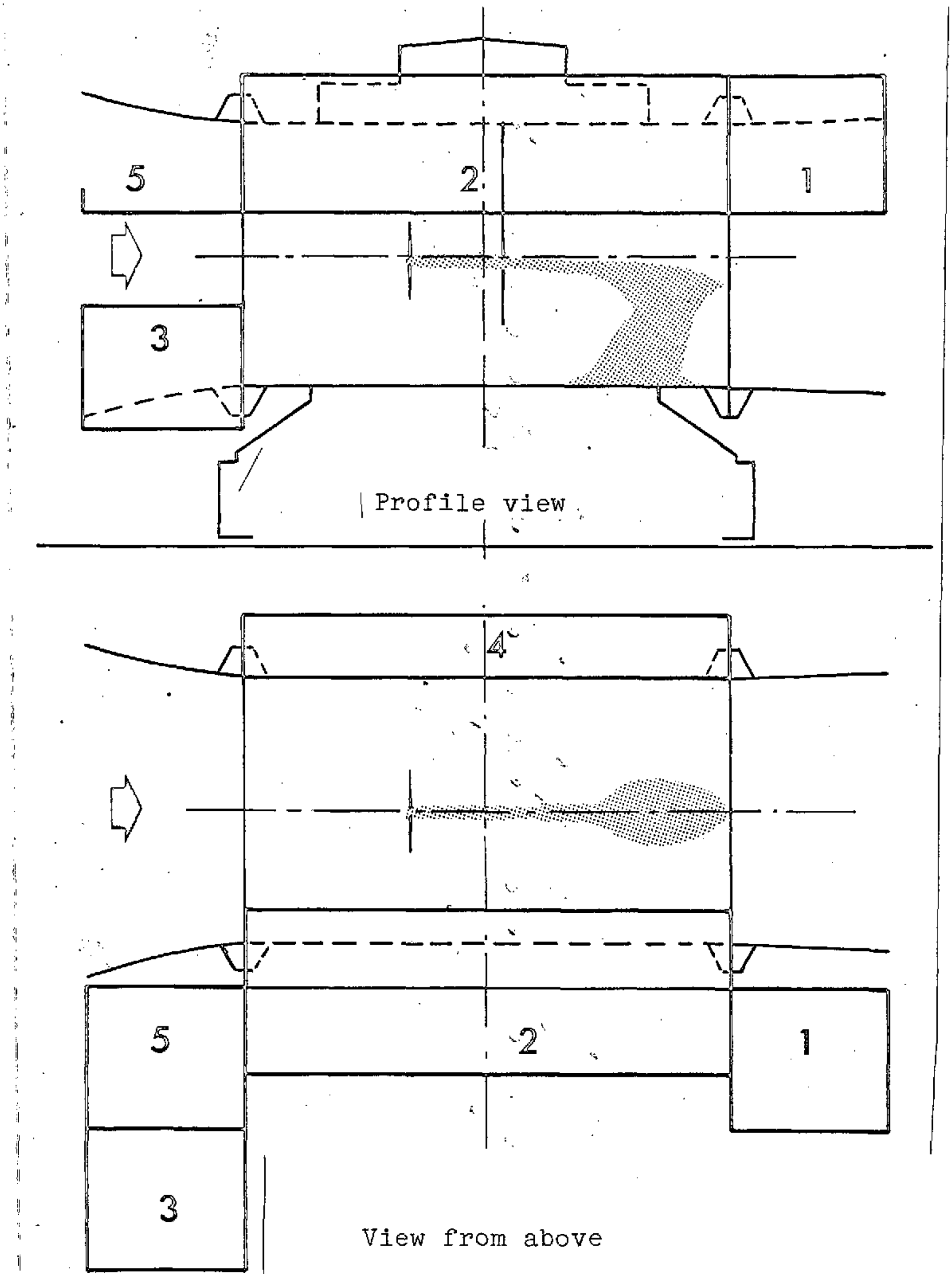


Figure 6. Arrangement of the various command posts and measurement stations with respect to the test section.
See next page for legend.

1- control and monitoring of the wind tunnel; 2- test direction; control and monitoring of the motor units and the shaft train; 3- local instrumentation: measurement acquisition; electrical monitoring of the installation and dynamic recordings; 4- stroboscopic visualization, photographs, etc.; 5- Pressure measurement platform using liquid multimanometers.

CII 10.020 computer installed in a separate building.

II.2. Test of the Propeller Alone (Configuration Called "Minimum Cylindrical Body") /7

The performance at present required by designers of propeller aircraft, and in particular by designers of STOL and VTOL aircraft (aircraft which takeoff and land over short distances or takeoff and land vertically) is such that it is absolutely necessary to test the propellers at a large cruise velocity, so as to be able to determine the influence of the compressibility phenomenon on their overall performances.

In the first phase of the project, predictions are made on the propeller alone which operates in a unform flow. In order to establish these conditions, the propellers are in general tested in the wind tunnel on a cylinder which is sufficiently elongated upstream and downstream of the propeller plane, so that the flow is perfectly uniform [5]. The hub of the cylinder is then masked by the upstream cylinder and the force measured is only produced by the propeller blades, if one takes into account the effect of the pressures on the upstream side and downstream side of the hub. This type of test section is called "minimum cylindrical body" (English: minimum body).

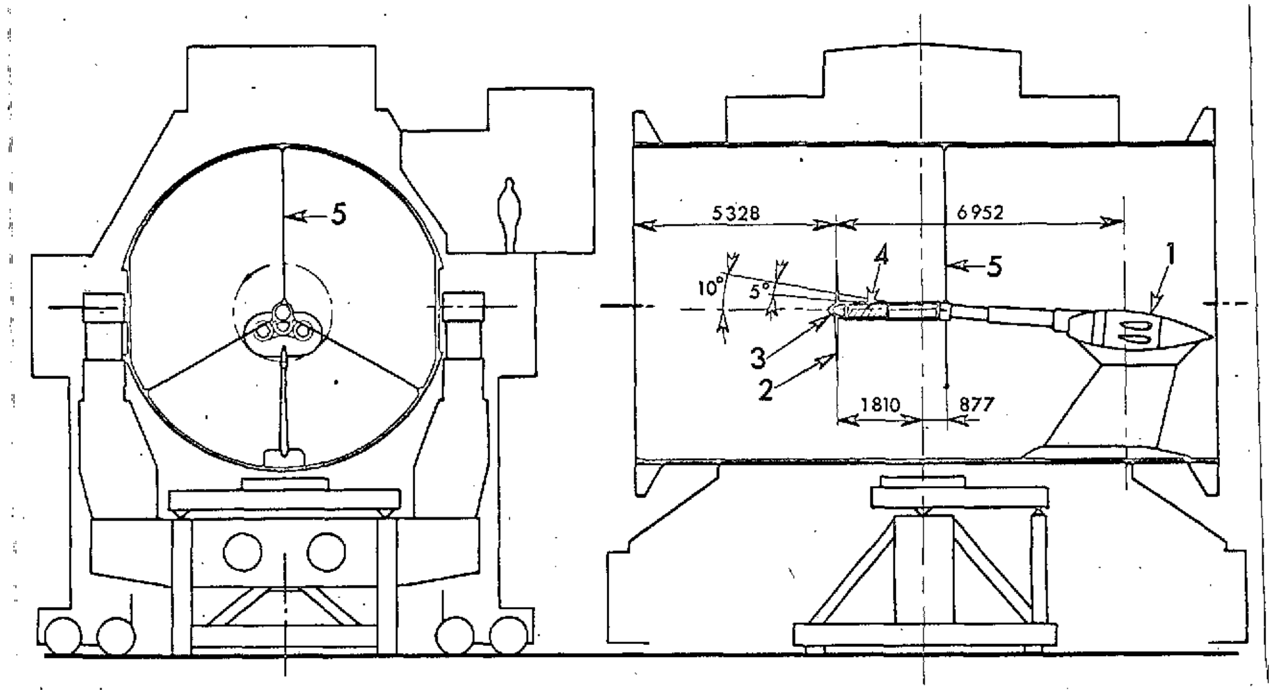


Figure 7. Propeller test stand in the "minimum cylindrical body" configuration.

1- motor unit; 2- propeller being tested; 3- forward tip; 4- balance; 5- wind brace.

The installation utilized at S1MA is designed according to this facility, but the upstream part of the cylinder is reduced to a propeller point forebody (fairing essentially semi-ellipsoidal, which covers the propeller hub) and the aerodynamic measured forces are the ones which are applied to the entire configuration: the propeller and the point forebody.

The downstream part of the cylinder contains the force measurement system and the drive shaft, and extends to a motor unit located about 7 meters from the propeller. This cylinder is supported by a sheet of three guide wires located 2.7 meters downstream from the propeller. Downstream of these guide wires, the motor unit and the cylinder containing the drive shaft are

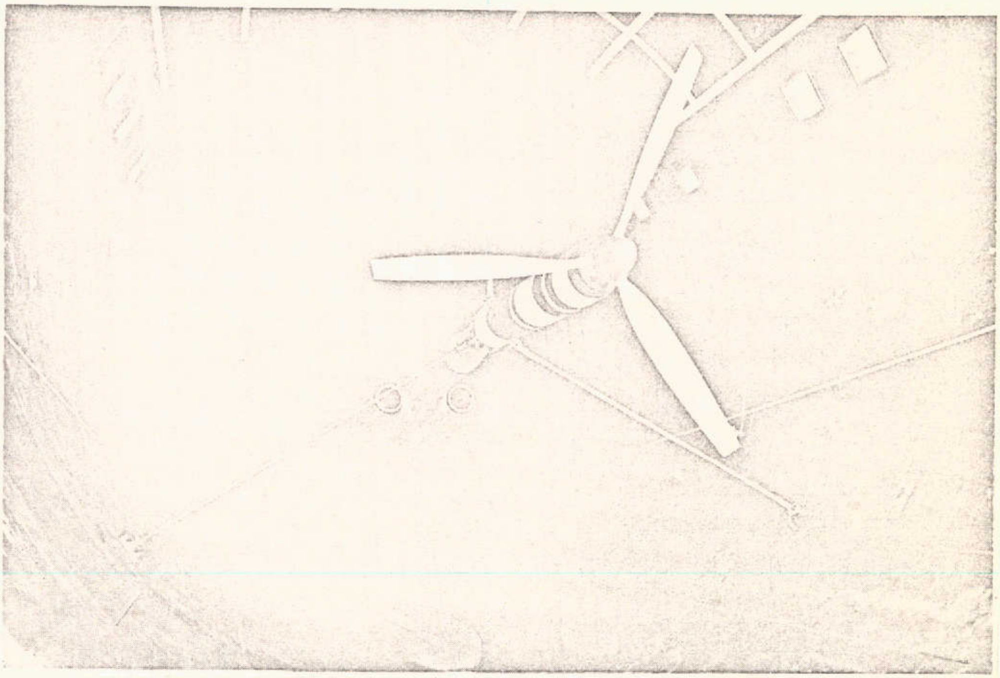


Figure 8. Test of a three-blade propeller for a bi-turbojet transport aircraft (real blades).

cocked at a 5° incidence angle. The upstream part of the cylinder can be set at any incidence angle between 0 and 10° (except for the value of 5°) (Figures 7 and 8).

This adaptation of the classical "minimum cylindrical body" installation is used primarily in smaller wind tunnels than the S1MA, but is justified here for technological and aerodynamic reasons. The dimensions of the S1MA wind tunnel and the desire to obtain large velocities generate mechanical holding problems for the upstream cylinder. On the other hand, the cylinder can only be held by a system of masts or guide wires. Therefore, it is difficult to predict the influence of their wake on the propeller performance. Finally, under theoretically ideal conditions, the pressures upstream and downstream of the hub are different and the propeller force must be corrected for this parasitic force.

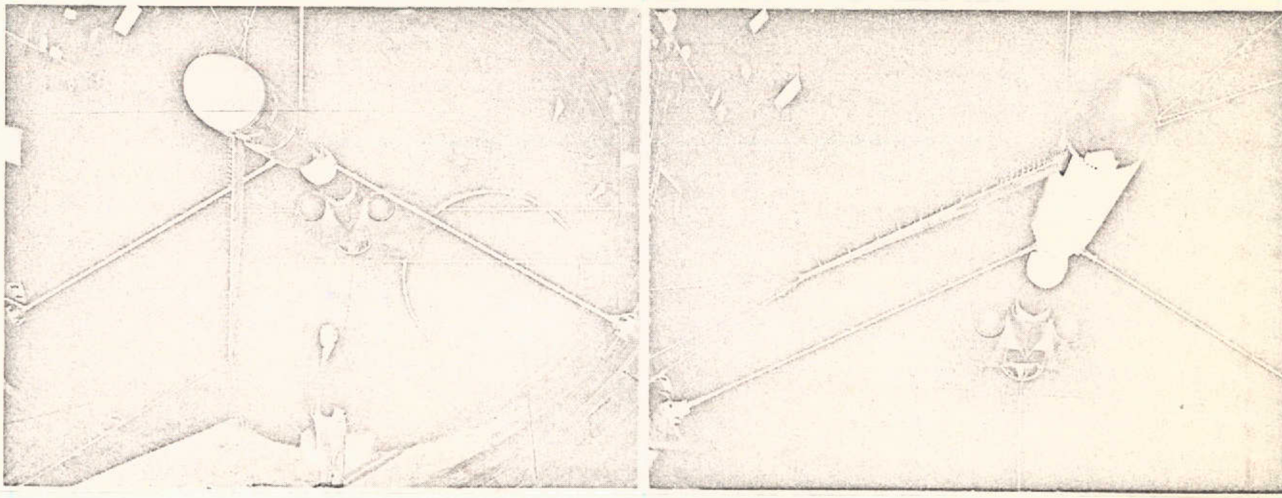
The solution adapted by the ONERA makes it possible to eliminate the technological difficulties. However, it is necessary to apply two types of corrections to the performance values in order to make them compatible with the calculation results. In effect, the raw measured force is equal to the force applied to the propeller alone minus the drag of the point forebody. Also, the presence of the point forebody produces a certain overvelocity in the propeller rotation plane with respect to the uniform field of the minimal cylindrical body. This means that the propeller force is slightly modified. The method consists of determining the drag of the point forebody in order to determine the force on the propeller alone from the total measured force. Also, the velocity field map in the propeller plane is drawn without this point forebody. /8

The drag of the point forebody consists of two terms:

— The form and friction drag, which is measured during a preceding test of the point forebody without the blades;

— The drag on the collar due to the difference between the pressure at the collar and the static pressure of the flow in general. These pressures are measured at each point of the measurement during the propeller test.

The velocity field map in the plane of the propeller is established using a rake consisting of pairs of static pressure probes and total pressure probes over a length corresponding to the propeller radius (Figure 9). By displacing the rake in the azimuth, it is possible to establish this velocity map for several radii of the circle which is described by the propeller, so as to verify the symmetry of the flow with respect to its axis.



a) azimuth $\psi = 180°$ b) azimuth $\psi = 120°$

Figure 9. Evaluation of the velocity field in the propeller plane along two radii.

The nonuniform nature of the velocity in the propeller plane /9 only poses problems in the case where the measured performances must be compared with the results of a calculation performed assuming uniform flow: this calculation must then be done over taking into account the real velocity distribution, but usually the resulting modification is quite small. On the other hand, it can happen that the designer in a very elaborate project wishes to know the performances of the propeller in the velocity field of the forebody designed for the project [6]. In this case, the installation can exactly simulate this requirement. By adding a system of variable permeability, obstructions on the cylindrical body upstream of the propeller is a method which can artificially produce the desired velocity field in a propeller plane, and has already been tested in experiments [2].

II.3. Propeller Tests in the Presence of Its Motor Cowling (Configuration: "Model Cowling")

In a general sense, it may be useful to know the propeller performance in its natural environment. Without making use of the many possibilities which could be installed in wind tunnels (see Chapter II.4: Tests of Convertible Propellers), it is possible to use a particular mounting for studying the propeller in the presence of its motor cowling (Figures 10 and 11).

In this test configuration, the model motor cowling is /10 supported by a wing which is diametrically suspended at its two extreme points by the wing tip balance of wagon No. 3. The propeller rotation is provided by the same motor unit as is used for the "minimum cylindrical body" tests. The wing tip balance produces the aerodynamic forces of the entire assembly: wing, motor cowling, and propeller. The performance values for the propeller alone are obtained using a special propeller balance installed in the motor cowling model. The possible incidence angles for the propeller are in the range between 0 and +10°.

We would like to recall the possibility of the wind tunnel for testing the propellers on their own motors. These are installed on a diametrically opposed wing in a configuration resembling the one described above ([4], page 18). Even though these tests are more accurate than the motor tests and even though the propeller is only studied afterwards, the propeller performance can be obtained with a reduced accuracy compared with the forces measured with and without the propeller. The measurement of the forces on the entire configuration is carried out by the wing tip balance, and after this, measurements of the forces acting on the motor group can be performed using a special balance between the group and the wing which is diametrically opposite to the supporting wing (Figure 12).

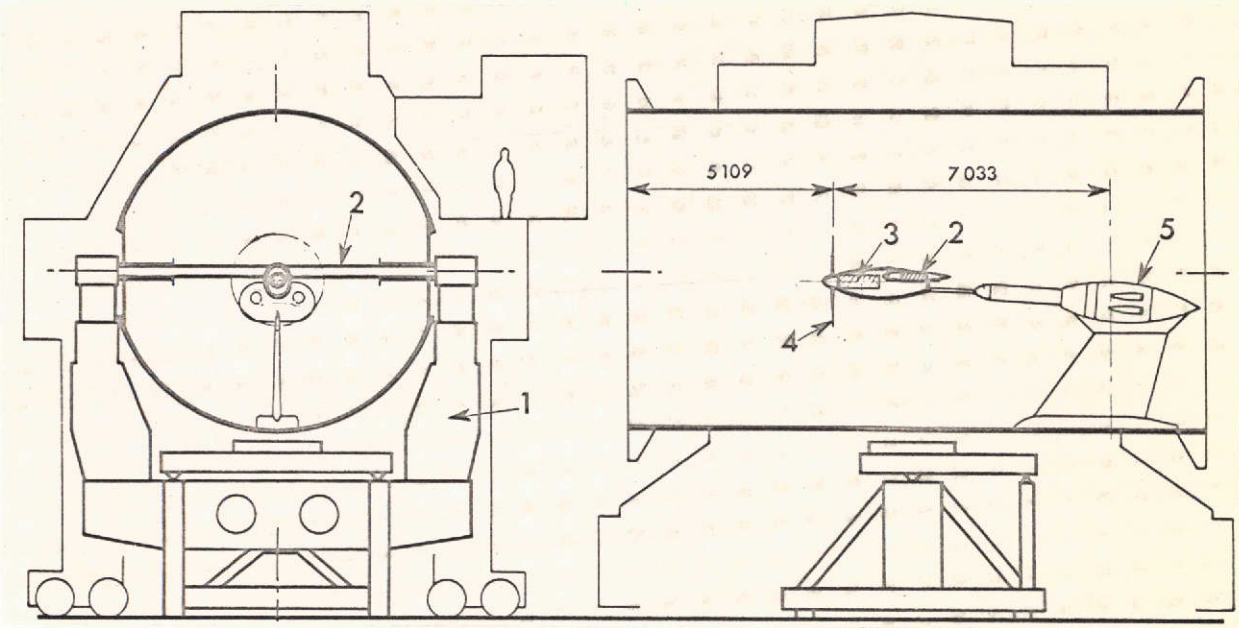


Figure 10. Propeller test on the model motor axis (obstruction and situation in the test section).

1- wing tip balance; 2- diametrically opposed wing; 3- propeller balance; 4- propeller; 5- motor unit.

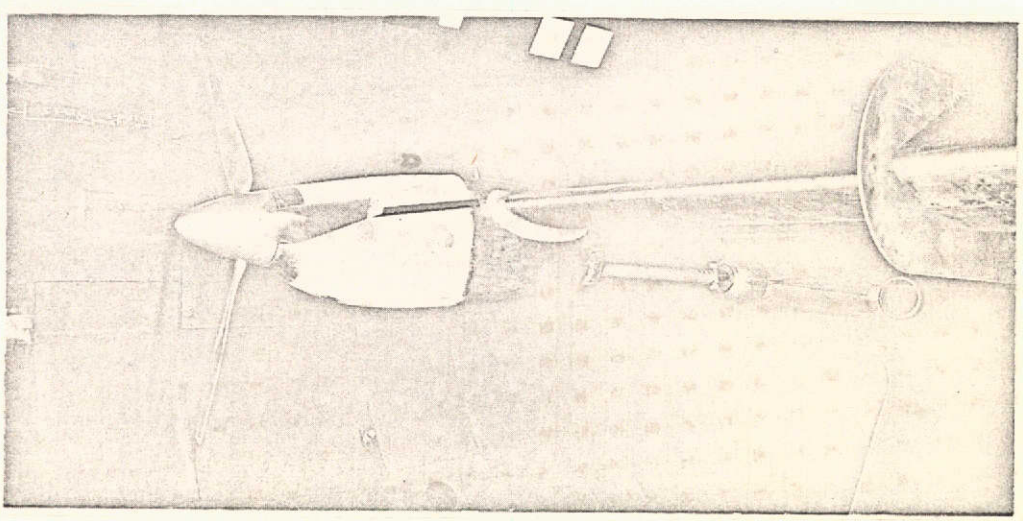


Figure 11. Test of a propeller of a ADAC at a scale of 1/1.8 on its model motor axis.

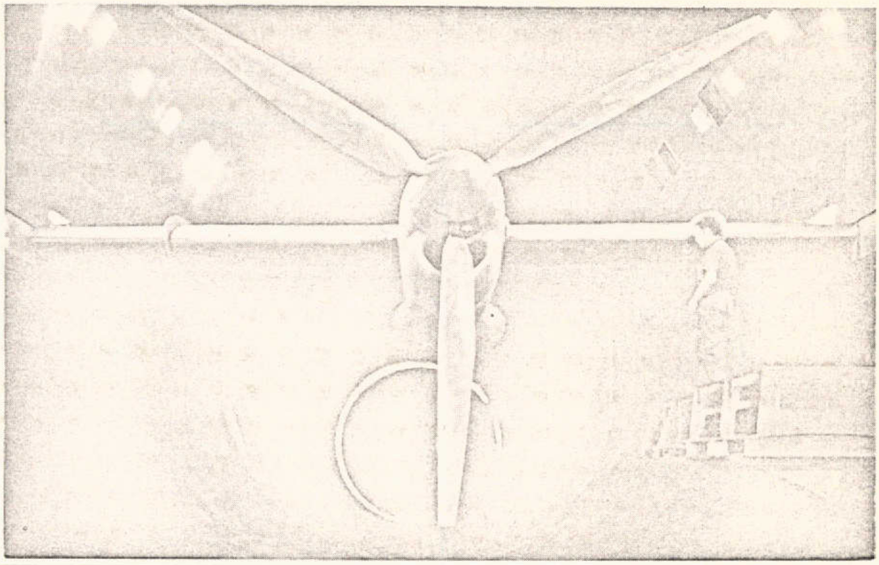


Figure 12. Test of a turbojet of the STOL with its propeller.

II.4. Tests of Convertible Propellers (Study of Transition from Vertical Flight to Horizontal Flight)

Since 1967, the S1MA wind tunnel has had a specially designed device, originally designed for helicopter rotor tests [3], which was adapted to convertible propellers, because the possible incidence range of the propeller axis is -5 to +115°. The same motor unit described above is installed at the tip of a mast which is shorter than the one used for the "minimum cylindrical body" installation. The shaft drives a variable incidence angle gear, installed on a second pointed mast. With this, it becomes possible to vary the propeller axis in a continuous fashion during the test. The cylindrical support, the entire force measurement system, and the propeller hub are those utilized for the tests with the "minimum cylindrical body" configuration (Figures 13 and 14).

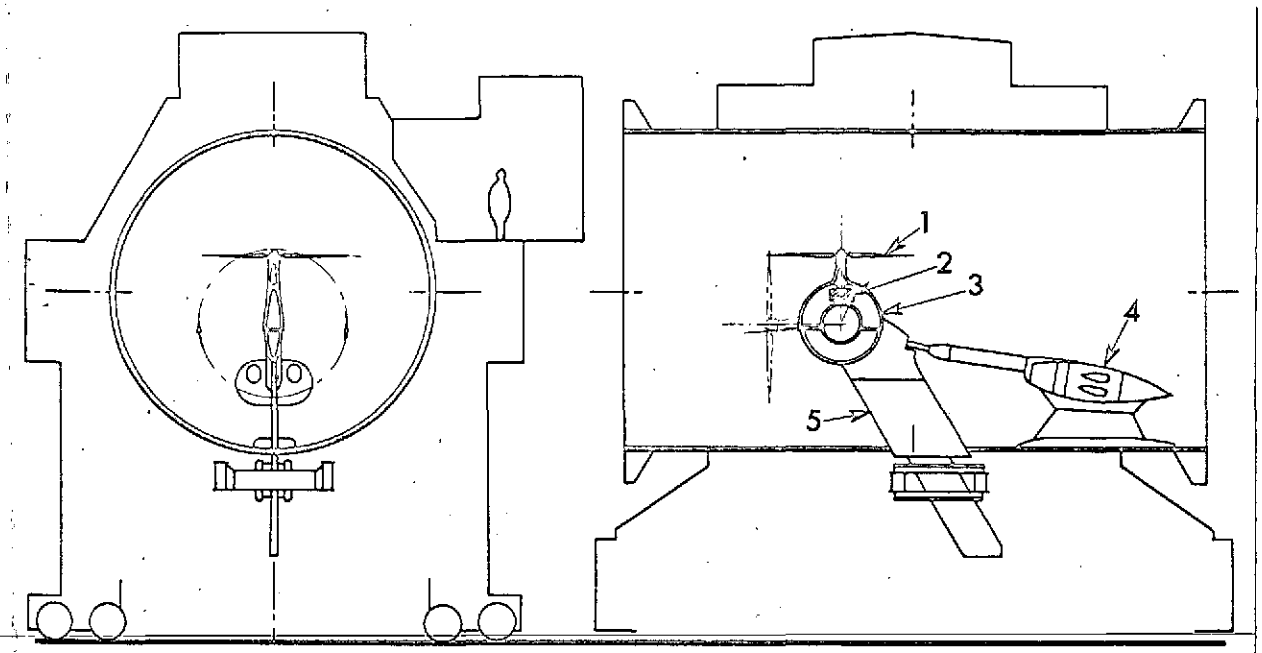


Figure 13. Test stand of convertible propellers in test section No. 2.

1- propeller; 2- balance; 3- angle; 4- motor unit; 5- supporting mast for angle gear.

The determination of the forces developed by the propeller alone, independent of the forces on the point forebody, is obtained in the same way as for the zero incidence tests using the "minimum cylindrical body" configuration: first determination of the aerodynamic coefficients of the point forebody without blades and then correction of the total measured forces with the propeller.

It should be noted that the exact incidence angle of the point forebody in the field of the rotating propeller is not directly obtainable. These corrections are difficult and not very accurate. Even though they are relatively small, because transition of a convertible propeller occurs at a low velocity, the ONERA studied a system with which it was possible to simultaneously measure the forces acting on the point forebody alone

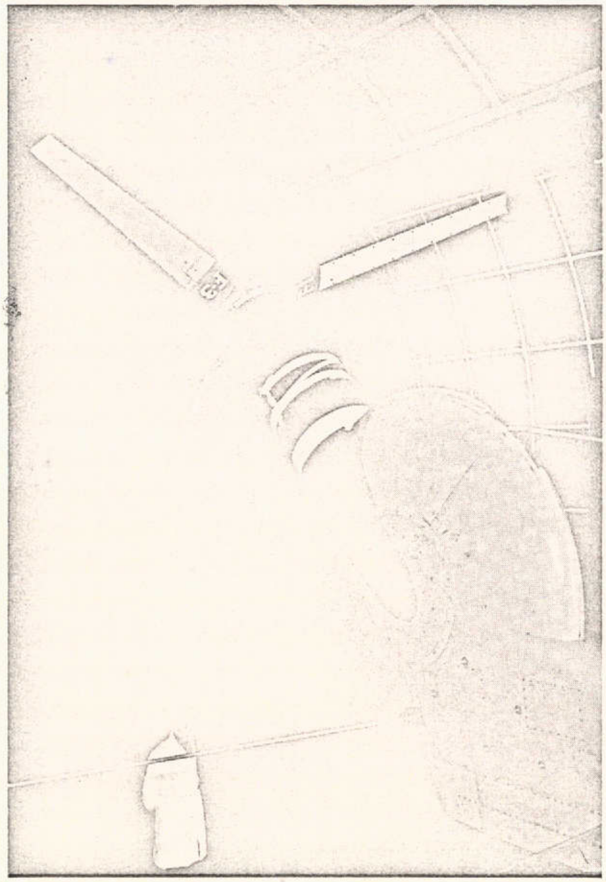


Figure 14. Test of a convertible propeller. (test "C") 45° incidence, hub furnished by the builder.

and the forces on the propeller and point forebody combination while rotating.

III. MOTOR UNIT AND MECHANICAL DEVICES /12

The mechanical part of the installation consists of a motor unit consisting of two coupled turbomotors, as well as various devices corresponding to the various possible tests: minimum cylindrical support, model motor cowling, angle gear for large incidence tests; the force measurement systems are adapted to these various cases.

III.1. Motor Unit

It is used in all of these tests and consists of two turbomotors with free turbines installed in parallel at the tip of a mast (variable height, depending on installation). They are coupled using a first reduction stage which reduces the rotation rate from 6,000 rpm at the free turbine output to 3,920 rpm at the transmission axis. An idler wheel installed at the output shaft of each turbine makes it possible for the unit to operate with one motor stopped. Flexible shafts protect the motors in case there is a failure in the transmission. The downstream extremity of the common transmission shaft has an electromagnetic brake which can be controlled and which can absorb (up to 60 kW)

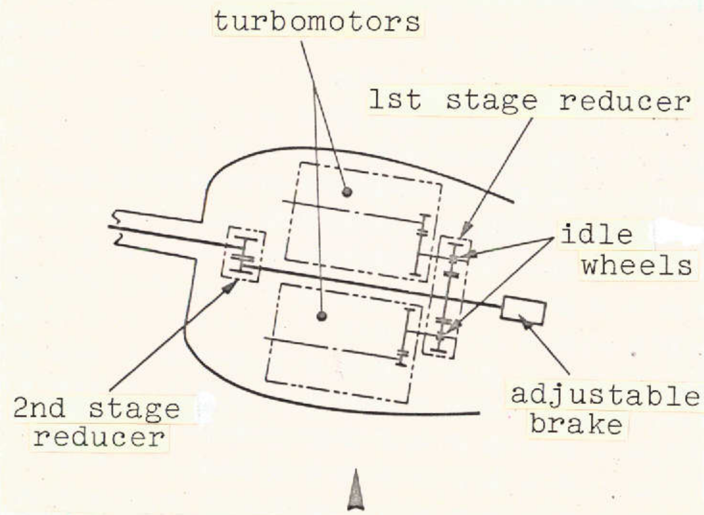


Figure 15. Kinematic diagram of the motor group.

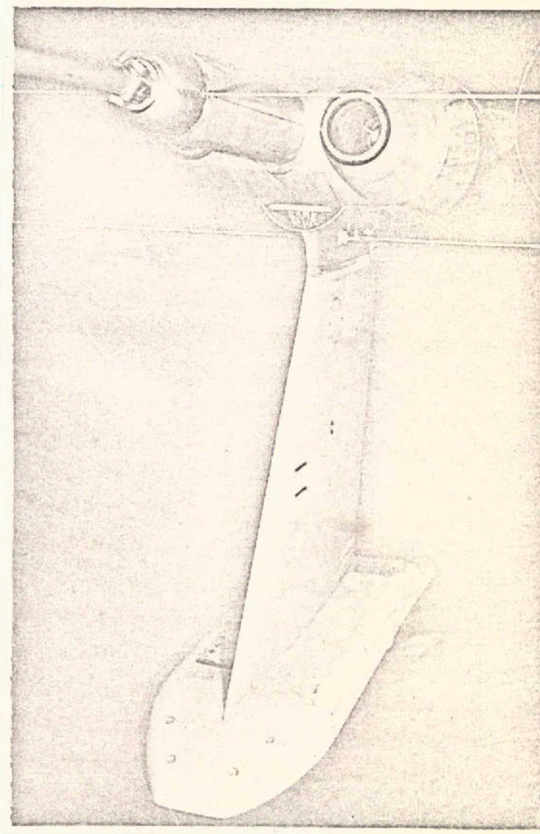


Figure 16. Motor unit.

the braking power of the turbomotors for autorotation tests. Also, it can be used to control the rotation rates during normal rotation.

Upstream of the motor unit and on the transmission shaft there is a second reduction stage which drives a cardan joint transmission. It transmits the power to the propeller with a maximum rotation rate of 2400 rpm.

This motor unit is installed on a support mast with a 5° incidence angle, in order to provide for the correct functioning of the cardan joints of the shaft train.

At the stationary point and under standard conditions, each of these motors has a power of 590 kW for a rotation rate of 34,000 rpm of the gas generator and 5325 rpm for the output shaft.

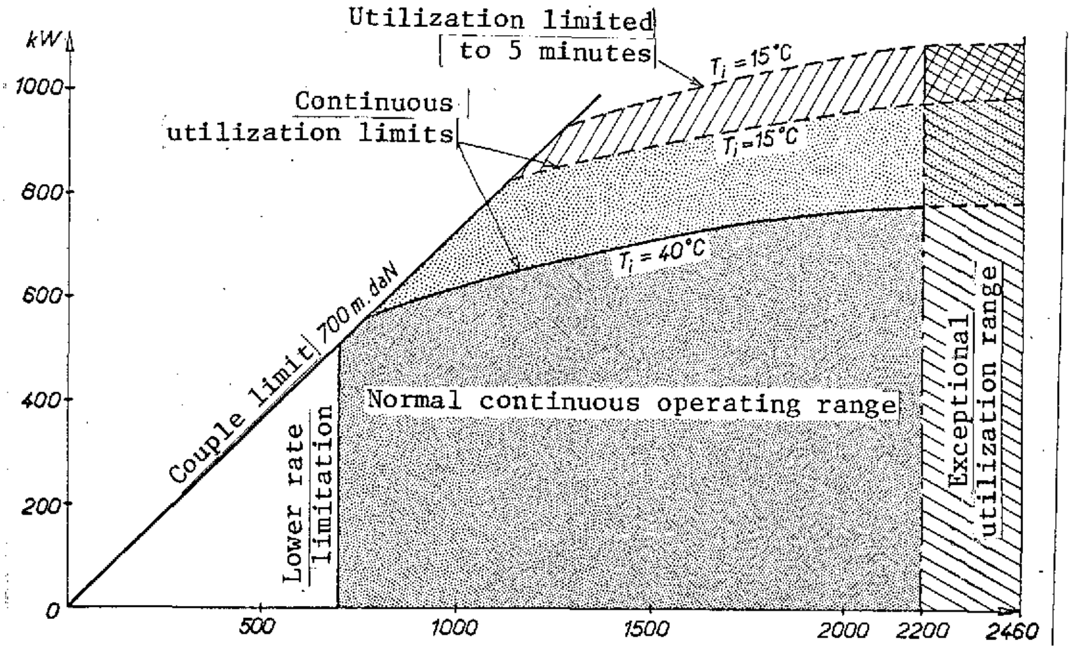


Figure 17. Performance of the device along the propeller axis. Rotation rate of propeller (rpm).

At Modane (altitude 1100 m), the maximum available power is 550 kW for each turbomotor, or 1100 kW for the motor complex for the same rotation rate conditions as mentioned above. Figure 17 gives the available power at the propeller shaft as a function of its rotation rate and as a function of the wind tunnel conditions. /13

III.2. Minimual Cylindrical Support (Figure 18)

This support consists of a cylindirical case which connects the motor unit to the propeller hub. This case is supported about 4 meters from the motor unit by a sheet of three guide wires having a diameter of 26 mm. Downstream of this guide wire system, it is maintained at a constant incidence angle of 5°, imposed by the motor unit. Upstream of the guide wire system, all the incidence angles between 0 and 10° can be set for this

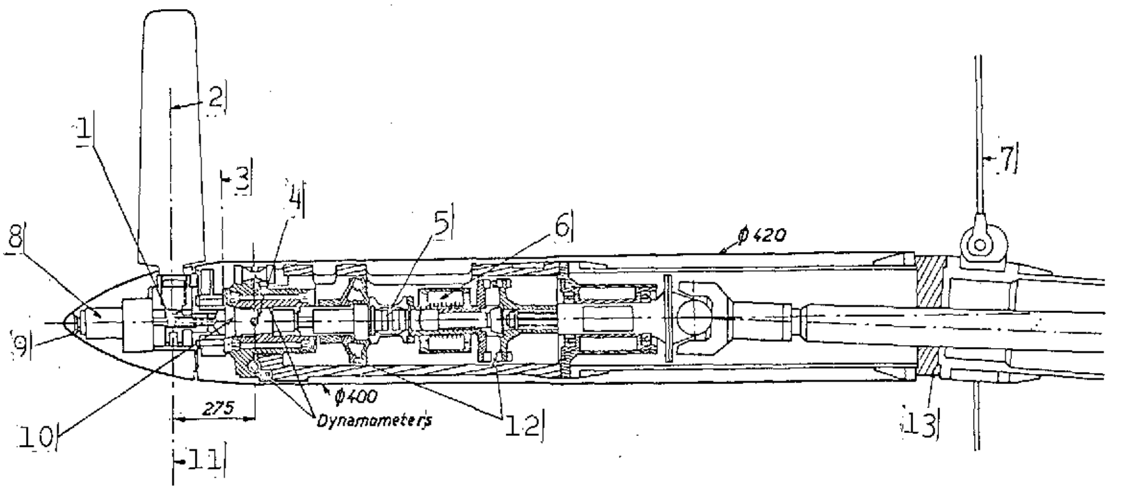


Figure 18. Details of mechanical installation of the minimum cylinder support.

1- propeller reduction center; 2- propeller plane; 3- forward balance plane; 4- balance reduction center; 5- coupling meter; 6- collector; 7- guide wires; 8- commanded reducing motor for the propeller pitch; 9- location of the weighing dynamometer of the forward rotation point; 10- propeller pitch indicator; 11- 1810 to the section axis, wagon III; 12- elastic couplings; 13- incidence wedge.

cylindrical case. This is done by inserting an incidence wedge located between two of these elements, at the level of the guide wires.

In the interior of this case, there is the axle line which provides for the motion transmission from the motor unit to the propeller. It consists of tube shafts installed on bearings with ball and socket joints. The change in direction at the level of the guide wires of this shaft train is provided by a cardan joint transmission, and which should not operate in a straight line. This restriction explains why it is forbidden to fix the upstream part of the cylindrical case at the particular incidence angle of 5°.

At the upstream extremity of the case, the force measurement installation is installed, called the "propeller balance No. 4," and which is described in Paragraph III.5.

Upstream of the propeller balance, the propeller blade supporting hub extends the drive shaft line by means of a channeled matching shaft. Two blade supporting hubs can be installed and are included in the equipment for the wind tunnel. These two hubs, three-blade and four-blade, respectively, have an electrical blade pitch control system (simultaneous pivoting of the blades around their axes). They have the following common characteristics:

Rotation rate: 2400 rpm maximum
Maximum angular deflection of the blades: -15 to +80°
Maximum centrifugal force acceptable per blade: $3 \cdot 10^4$ daN.

Under these conditions, the triple hub has a force of 1500 daN for a couple of 500 m. daN. The four-blade hub has a force of 2500 daN for a couple of 750 m. daN.

The transmission of the electrical energy for the pitch changing motor and the various electrical signals between the fixed part of the installation (case) and the rotating part (hub) is provided by two sliding contact collectors: One of them is radial and is used for high intensities. The other is axial and has 15 tracks reserved for the lower level electrical signals.

The two hubs are covered by the point forebodies which is dictated by the diameter of their collar, the diameter of the fairing installed on the cylindrical case. The overall diameter of the cylindrical support is 400 mm in the case where the normal wind tunnel is used.

Besides the channeled adaptation shaft, other types of hubs can be installed on the test stand. The diameter of the fairing of the cylindrical case downstream of the propeller depends on the type of point forebody used. This possibility is illustrated for convertible propeller tests "C"* (see Chapter V.3) with a three-blade hub supplied by the designer. The diameter of the fairing of the cylindrical case was 577 mm. /14

III.3. Model Motor Cowling (Figure 19)

For this type of test, the motor cowling model contains the propeller balance, the "second stage" reducer, which is required here in order to provide a good functioning of the transmission line with cardan joints. This reducer can be used to transmit a power of 1600 kW at 2400 rpm, in order to provide for a possible coupling of the motor unit power at this level. The propeller drive is provided by the motor unit already discussed through a ball bearing coupling located between the motor part and the transmission.

The motor cowling is supported at its two extremities by means of a wing tip balance (motor balance). The incidence angle for the cowling ($0° \leq i \leq 10°$) is provided by the inclination and vertical translation of dynamometric cylinders.

Using the sliding coupling with ball bearings between the motor unit and the propeller, the maximum drag interaction is 18 daN for the maximum coupled value. /15

Finally, it should be noted that for small dimension cowlings, various reduced dimension elements are available. In particular, there is a second stage reducer with a power limitation of 1100 kW.

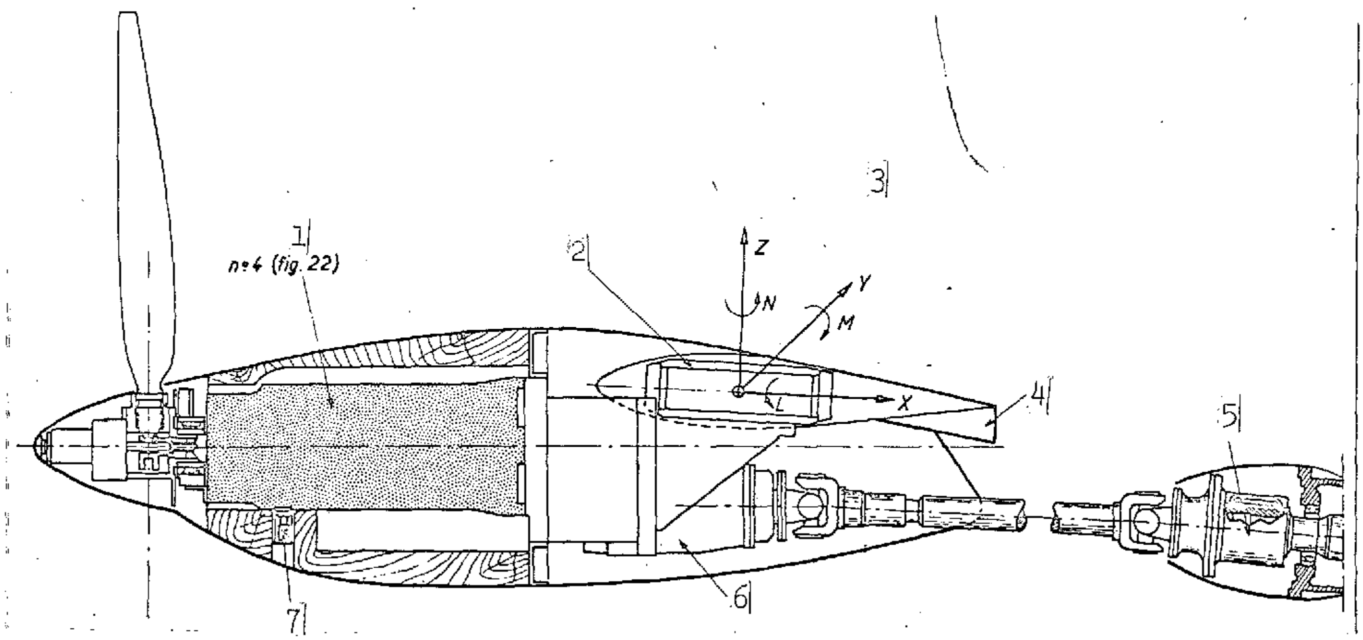


Figure 19. Details of the mechanical installation of the modeled motor axle.

1- propeller balance; 2- transverse support beam streamlined according to wind profile; 3- weighed forces exerted by the dynamometer case of the balance for motor tests; 4- compensating flap; 5- ball bearing coupling; 6- second stage reducer (reduction ratio 1/1.586); 7- goniometer.

III.4. Large Incidence Propeller Tests [3] (Figure 14)

The propeller axis can be given incidence values between -5 and 115°. This is done by installing an angle gear with conical pinions to the drive shaft. Its angle can be changed continuously (Figures 20 and 21). The commands are given during the test from the measurement room.

In this configuration, the motor unit is located at the tip of a mast which is lower than in other installations.

The angle gear inverts the direction of rotation and the second stage reducer is modified so as to give the propeller the same direction of rotation as in the other installations.

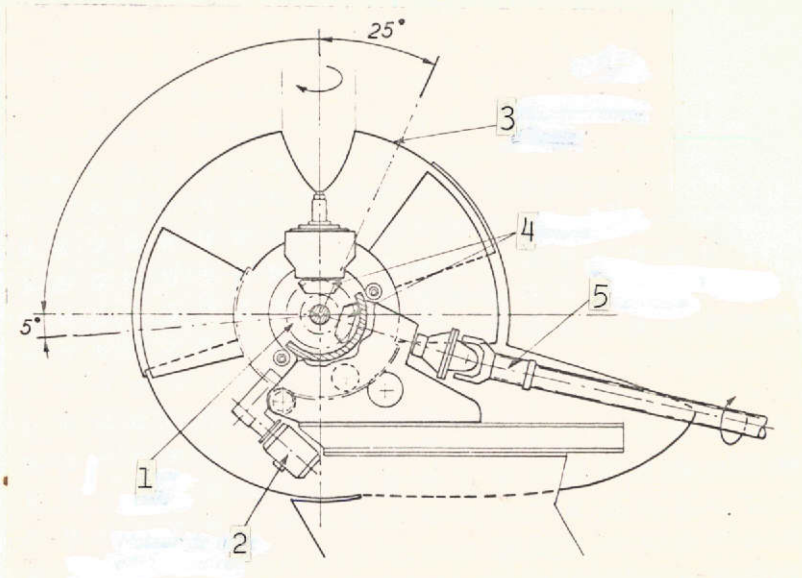


Figure 20. Detail of the mechanical installation of the angle gear.

1- idler wheel; 2- incidence setting motor; 3- angle gear fairing; 4- pins; 5- cardan transmission.

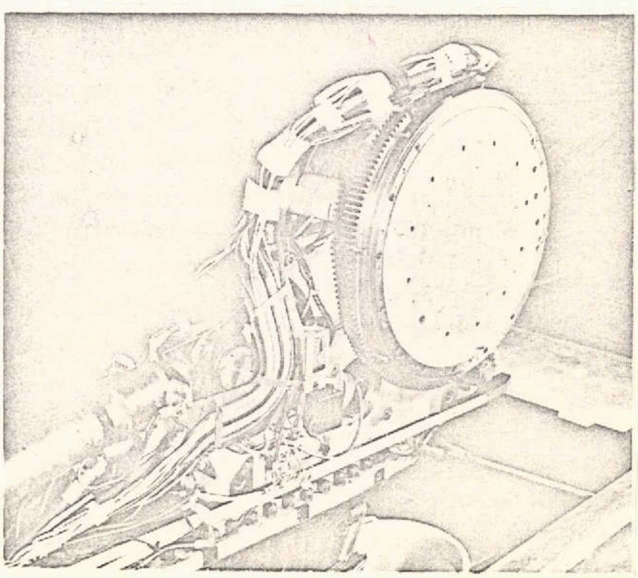


Figure 21. Angle gear, fairing and case removed.

The cardan transmission already described is again used for transmitting the power to the angle gear. This angle gear is installed at the tip of a tapered mast and consists of a thick case and a case which can be inclined around the horizontal axis for the incidence setting. A conical idler wheel around this axis transmits the power from the input pinion to the output pinion connected through the drive shaft of the propeller hub. The propeller is set at incidence by means of a variable rate electrical motor. A hydraulic brake with jaws clamped the rotatable case in the selected position, and this is measured by means of a potentiometer transducer.

The entire unit is protected by an ellipsoid of revolution bearing and is supported by a mast with lateral guide wires.

Upstream of the angle gear, the cylindrical case which contains the drive shaft is extended by the propeller balance (balance No. 4) and the propeller hub. The configuration is similar to the one used for the "minimum cylindrical body" configuration.

III.5. Force Measurement Systems /16

For the tests with the model cowling, the total forces on the propeller and the cowling are measured using the wing tip balance. For all of the tests, the forces for the propeller and the point forebody are provided by a special balance called "propeller balance No. 4." The forces on the point forebody alone are provided by a special balance.

III.5.1. Wing Tip Balance

During the propeller tests with the cowling model, the total drag is measured using the wing tip balance, which has been designed for motor tests and which is utilized to support the wing. This balance has a capacity above the requirements of the propeller tests:

Lift:	-8,000 to +20,000 daN
Roll moment:	± 8,000 m. daN
Drag:	-10,000 to +8,000 daN
Pitch moment:	± 8,000 m. daN
Side force:	± 2,000 daN
Yaw moment:	± 3,000 m. daN

The measurement accuracy varies between 0.2% and 0.5% of the measurement range. In the lower third of the drag range, which essentially corresponds to the range of propeller tests, the accuracy is on the order of 0.5%. The small vibrations or small motions of the model during the test make the interactions due to the ball bearing coupling between the motor unit and the transmission negligible.

III.5.2. Propeller Balance No. 4

Up to 1968, the propeller balances used (balances Nos. 2 and 3) could only measure the force and the couple of the propeller [2]. They were only suitable for tests with zero or small incidence angles, using "minimum cylindrical bodies."

Because of the requirement for testing adjustable propellers at large incidence angles, the ONERA constructed a new balance (No. 4) having six components with an attached couple meter, which was used after 1969 (Figure 22).

It consists of two parts which are essentially independent: the couple meter and the six-component dynamometer unit.

The dynamometer unit with six components (or six-component balance) consists of three coaxial cylinders:

— The first cylinder with the smallest diameter is rigidly attached to the drive shaft of the propeller and turns with it.

— The second one with fixed rotation is connected with the first one by means of a ball bearing unit and ball bearing support.

— These two cylinders, which are rigidly connected with the propeller through the drive shaft, constitute the "weighing" part of the balance. The balance itself is uncoupled with respect to force from the downstream part, the non-weighing part, and from the shaft line using two "flectors" located to each side of the couple meter unit. These two flectors have negligible rigidity in the force direction and a very high rigidity for couple measurements. Therefore, they provide the continuity of the drive shaft for transmission of the rotation motion to the propellers without interaction of the force from the downstream part of the installation.

— The third cylinder, rigidly connected with the cylindrical case, constitutes the sixth part of the balance. It is connected with the weighing part by means of six dynamometers which represent the sensitive elements.

The six dynamometers are different depending on their locations within the balance (Figure 22). The three dynamometers T_1, T_2, and T_3 are parallel with the rotation axis of the propeller and are called the longitudinal units. They measure the thrust, pitch moment, and yaw moment. The three dynamometers Z_1, Z_2, and Y make up the three sides of an equilateral triangle in a plane which is perpendicular to the propeller rotation axis. These measure the lift force, the side force, and the roll moment.*

*The roll moment measured by the six-component balance is the friction resistance couple in the rollers. [Illegible] a correction must be made to the measured couple, measured by the couple meter located downstream.

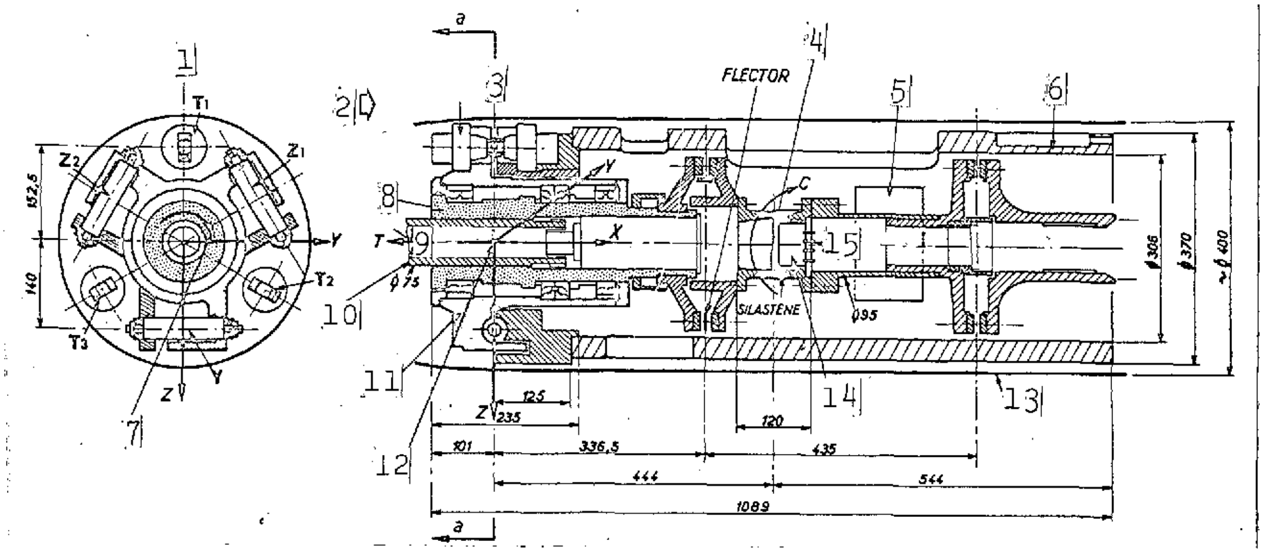


Figure 22. Diagram of propeller balance No. 4 (T_1, T_2, T_3, Y, Z_1, Z_2: six removable dynamometers.
1- section a (view in pilot direction); 2- wind; 3- six-component balance; 4- couple meter, 175 or 350 m daN; 5- nine-band collector; 6- cylindrical case; 7- rotation direction; 8- rotating weighing part; 9- propeller thrust; 10- channeled adaptation shaft for propeller hub; 11- fixed weighing part; 12- balance force reduction center; 13- fairing; 14- integrated electronics; 15- contact brushes.

These six dynamometers are interchangeable and their capacity represents the capacity of the entire balance. Therefore, by properly selecting the dynamometers, the accuracy can be increased by adapting the balance capacity to the type of test for the type of propeller.

These dynamometers, which are of the "force-compression" type, can measure a positive or negative force along their axis. They are equipped with 350 Ω strain gauges and an automatic compensation system for thermal effects, which produce zero offset and variations in the calibration coefficient by modifying Young's modulus. The strain gauges are installed in two Wheatstone bridges which are independent. This means that valid /17

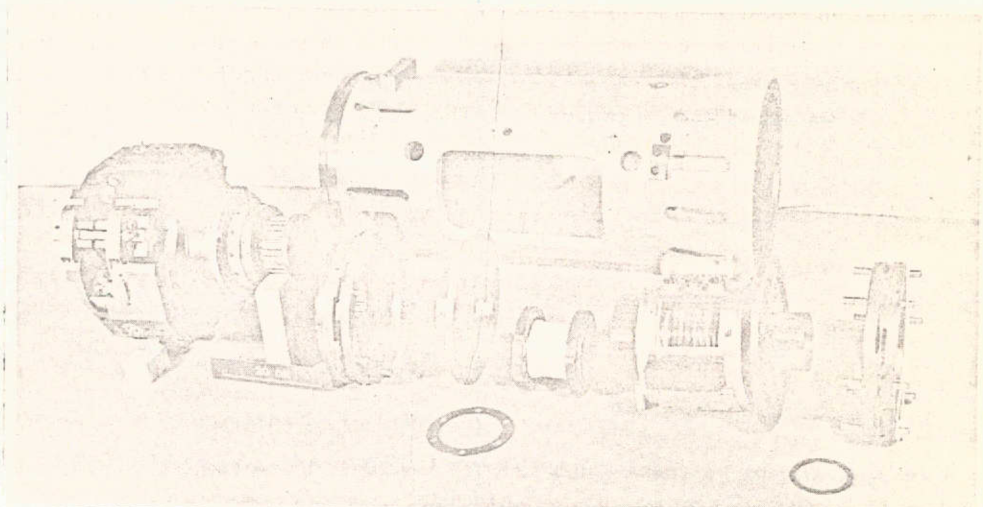


Figure 23. Exploded view of the balance unit.

measurements can be made even if one of the bridges deteriorates during the tests.

The two dynamometer units mentioned below are utilized on the balance during the tests:

— capacity of

T_1 : 1000 daN	Z_1 : 250 daN
T_2 : 500 daN	Z_2 : 250 daN
T_3 : 500 daN	Y : 250 daN.

— capacity of

T_1 : 500 daN	Z_1 : 250 daN
T_2 : 250 daN	Z_2 : 250 daN
T_3 : 250 daN	Y : 250 daN.

These two dynamometer units give the balance the following range, referred to its geometric center

T = 2400 daN	L = 230 m. daN
Y = 810 daN	M = 370 m. daN
Z = 930 daN	N = 210 m. daN

T = 1200 daN	L = 230 m. daN
Y = 810 daN	M = 180 m. daN
Z = 930 daN	N = 100 m. daN.

The measurement accuracy is 0.1% of the range.

The second element in the propeller balance No. 4 consists of a unit for measuring the motor torque applied to the propeller.

This unit, isolated in the upstream and downstream directions by two flectors, constitutes one part of the drive shaft for the propeller and is located downstream of the six-component balance (Figures 22 and 23).

It consists of a tube type couple meter and a sliding contact collector.

The couple meter is a thin tube, upon which there are glued 45° extension strain gauges installed in a Wheatstone bridge. Each branch of the bridge has two diametrically opposed extension strain gauges on the tube. The electrical signal representing an imbalance in a bridge under the effects of torsion is preamplified by an integrated amplifier located inside of the couple tube. Then it is transmitted to the fixed part of the installation through the collector. This collector is a sliding contact collector with silver/graphite-silver, nine-track contacts.

Depending on the test requirements, it is possible to install a nominal couple meter with a capacity of 350 m. daN (maximum couple 700 m. daN), or a couple meter with one-half the capacity: 175 daN nominal, 350 daN maximum. The measurement accuracy is always 0.1% of the nominal capacity.

Each of the elements of propeller balance No. 4 is separately calibrated under all of the thermal and dynamic conditions which can be encountered during the tests. Then the entire balance is installed under conditions similar to those in the wind tunnel tests and is then subjected to a thermal and dynamometric /18

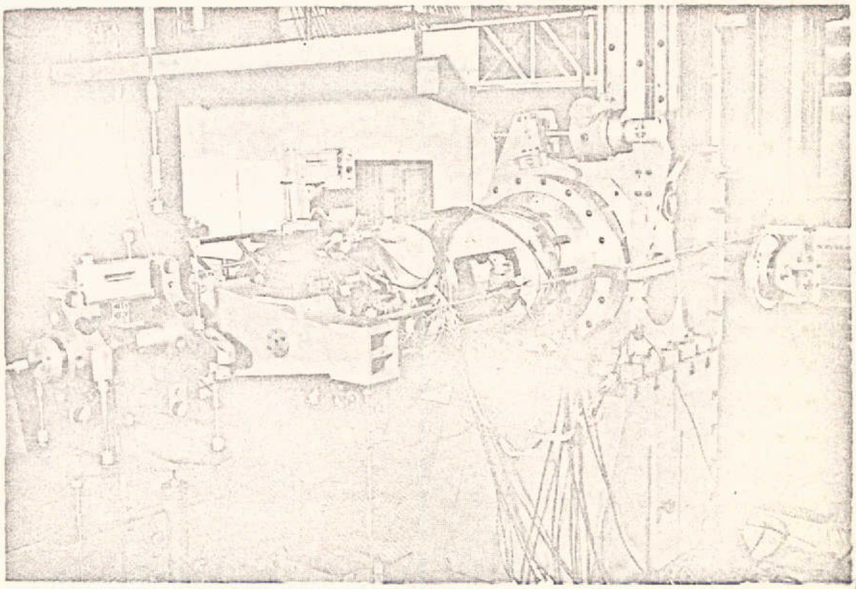


Figure 24. Calibration of the No. 4 propeller balance.

calibration ([4], page 15) (Figure 24).

This balance is very satisfactory because of its rigidity, and the fact that it is easy to operate and is very accurate.

III.5.3. Point Forebody Balances (see Figure 26)

Up to the present, measurements on the point forebody were primarily made using a three-component balance, previously used for other tests. For the convertible propeller tests "C" (see Paragraph V.3 below), the designer which supplied the point forebody studied and built a drag measuring dynamometer in collaboration with the ONERA. In the future, we plan to study and build a special balance, which can be used for all standard point forebody tests at the ONERA.

IV. INSTRUMENTATION, MEASUREMENTS, AND ANALYSIS

The measurements to be carried out during a test are the following: /19

— the preliminary measurement of the aerodynamic characteristics of the point forebody and the velocity field in the plane of the propeller;

— the measurement of the propeller performance;

— the monitoring of the dynamic behavior of the installation and the propeller being tested;

— additional measurements, in particular those used for stroboscopic procedures.

IV.1. Test Methods and Measurement Techniques Used During Preliminary Tests

These preliminary tests are necessary for determining the performance of the propeller alone (see Chapter II) and represent an initial study of the test installation [6]. They are indispensible each time a new assembly is built (in general, a new type of point forebody). This includes two types of measurements:

— determination of the aerodynamic characteristics of the point forebody;

— determination of the velocity field in the propeller plane.

The aerodynamic characteristics of the point forebody are measured using orifices in the closed-off blade bases and with the hub standing still. The point forebody is fixed with respect

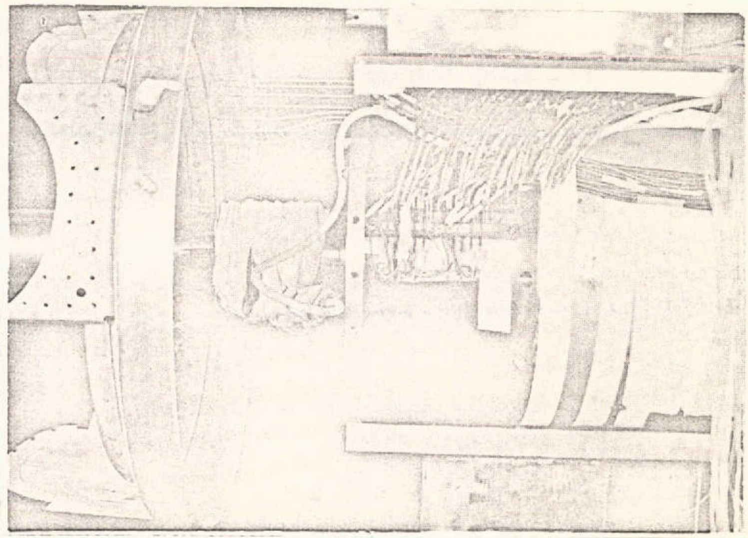


Figure 25. Detail of the installation — weighing of the point forebody and measurement of the sleeve pressure.

to the propeller balance by means of a "dynamometer spindle." It is fixed in the position which it has during the tests with the propeller.

A rake having several static pressure taps is used to determine the pressure at the sleeve (Figure 25).

The dynamometer spindle with three (ø 40 No. 3 M) gauge brdiges provides for the measurements of drag, lift, and pitch moments, under the different planned test conditions of the propeller. The measurement of the pressure field at the sleeve makes it possible to apply a correction of the sleeve drag to the measured drag. This measurement is recorded during the tests with the propeller, in order to also take into account the drag of the sleeve for determining the force of the propeller alone.

During the tests, the various parameters are measured using the same technique as the one utilized during the tests with the propeller. This is explained in the following paragraph.

The velocity field in the propeller plane is measured using a rake consisting of 25 pairs of (static and total) pressure taps. The measurements are carried out using water multi-manometers, and photographs are made at each stage of the measurement (Figure 26 and Figure 9, page 11). /20

Remark. The presence of the cylindrical support in the test section produces a slight overvelocity of the flow in the propeller plane. During the preliminary tests, it is possible to evaluate the exact velocity in the propeller plane by measuring the static pressure in this section of the test section. This pressure tap can interact with the rotating propeller. Therefore, the pressure measurement is carried out during the tests with the propeller in a region about 3 meters upstream from it.

The measurement of the static pressures in these two areas during the preliminary tests makes it possible to establish the relationship between the two pressures for us to be able to correct the velocity measured upstream of the propeller during the tests with the propeller. In this way, it is possible to derive the reference velocity (velocity "at an infinite distance upstream") in its plane of rotation.

IV.2. Measurement of Propeller Performances

At each test point, the performance of the propeller is determined from the following parameters:

— the reference variables of the flow in the wind tunnel:

t_i = generating temperature;

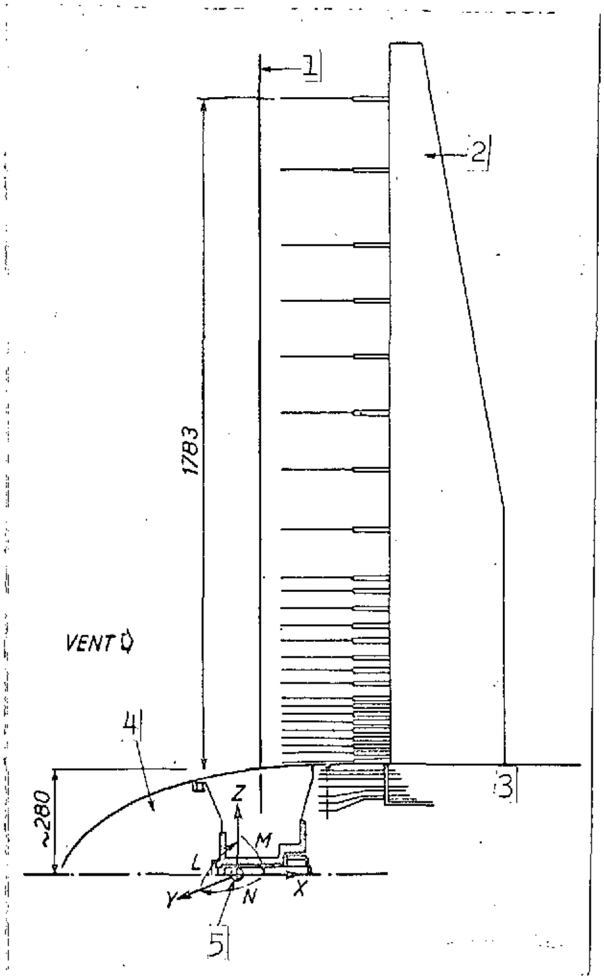


Figure 26. Diagram of the 50-probe rake (velocity field in the propeller plane) and dynamometer installation of the point forebody.

1- propeller plane; 2- large rake; 3- rake 30 [illegible] above the horizontal plane; 4- point forebody; 5- reduction center of the point forebody balance.

p_i = generating pressure;

p = static pressure;

Δp_ν = deviation between the static pressure measured in a double venturi and the generating pressure (this quantity is only used for low velocity tests, in order to have better accuracy),

— the characteristics on the operation of the propeller:

β = propeller pitch;

i = inclination of the propeller axis;

N_H = propeller rotation rate;

p_K = pressure at the sleeve of the point forebody.

— measurement of the forces: determined from seven strain gauge bridge signals, six temperatures in the balance (possibility of thermal corrections).

Among these quantities, p and p_K are each taken from two measurements. In addition, it is necessary to number each measurement point, so that a total of 28 quantities must be recorded for each measurement point.

IV.2.1. Measurement Technique

— The generating pressure which varies very slightly during /21
the tests and remains close to the atmospheric pressure ($p_a < p_i < p_a + 100$ daPa), is taken from a nacelle located in the test section axis of the wind tunnel settling chamber. The measurement is provided by a high accuracy absolute balance with a large response time.

— The generating temperature is measured by a thermocouple and the hot junction is placed in the same nacelle.

— The static pressure is measured at the wall of the section or on a static pressure probe in a test section region located about three meters upstream from the propeller plane. This configuration avoids possible interactions of the propeller and the pressure probes. The slight overvelocity created by the test installation in the test section is measured during preliminary tests. It is possible to find the velocity in the propeller plane from a measurement of the velocity upstream of the propeller.

In the case of low velocity tests ($V < 30$ m/sec), the velocity is measured with a better accuracy by using a venturi double tube.

The static pressure (or the difference between the static pressure in the venturi and the generating pressure), which can vary rapidly between two test points, is measured by a differential, short response time manometer capsule. However, it has a low capacity: ± 700 daPa. The adjustable counterpressure is essentially constant and is measured for each test point by a high accuracy absolute balance of the same type as the one used for measuring the generating pressure.

— The pressure at the sleeve at the point forebody is measured using seven pressure taps located along a radius of the sleeve of the point forebody (Figures 25 and 26). Six of these seven taps are connected to a multimanometer containing water which can be photographed. This makes it possible to verify the homogeneity of the pressure inside of the point forebody.

The seventh pressure tap is connected with a low capacity manometer capsule (±700 daPa), similar to what is used for static pressure. This manometer capsule is located inside of a box suspended by soft springs and connected to the cylindrical case of the propeller balance.

— The pitch of the propeller (β), which describes the position of the blade around its axis, is given by the angle of the profile of the blade located at 75% of the radius along the horizontal plane, when the blade axis is in this plane. This angle is measured either by a potentiometer located at the base of the blade (special hubs), or by a "selsyn" transmitter located in the hub axis ("standard ONERA" hub). The potentiometer outputs are transmitted to the fixed part of the installation through a sliding contact collector. The indications are read on a digital voltmeter during the tests and are transmitted to the measurement chain where they are recorded for each measurement point.

— The incidence angle of the propeller axis, when it is different from zero, is recorded by a potentiometer.

— The rotation rate of the propeller is measured in two ways. For monitoring and carrying out the tests, a transducer provides summed pulses by means of an electronic counter over a determined time base. For the measurements, the rotation rate of the propeller is recorded at each measurement point. It is measured by means of a quartz clock which determines the time between two successive pulses produced by an electromagnetic transducer each time the propeller rotates.

— The forces applied to the propeller are measured by the No. 4 balance propeller unit described in the preceding chapter. At each measurement point, one records the seven electrical signals which represent the unbalance of the seven dynamometer and couplemeter strain gauge bridges, as well as the six temperatures of the dynamometers measured by the thermocouples (copper-constantan). These temperatures make it possible to correct the electrical signals produced by the gauge bridges for small residual thermal effects.

IV.2.2. Acquisition Technique

The various quantities measured during the recording of one test point and translated into electrical form are stored at a central point in the instrumentation room. This room contains the electronic equipment (Figure 27) with which it is possible to transform all of the information into punched tape form as rapidly as possible. This punched tape is then analyzed by the computer at the Center, and then the final results are produced.

For each measurement point, 28 quantities are recorded. Except for the measurement point number and the propeller rotation rate, all the quantities (22) are filtered using resistance-capacitance type passive systems with a time constant of about 1.5 seconds. Of these 22 quantities, ten can vary during the measurement point acquisition time (7 signals from propeller balance No. 4 and 3 signals of the manometer capsule signals), which means that they must be simultaneously placed in memory

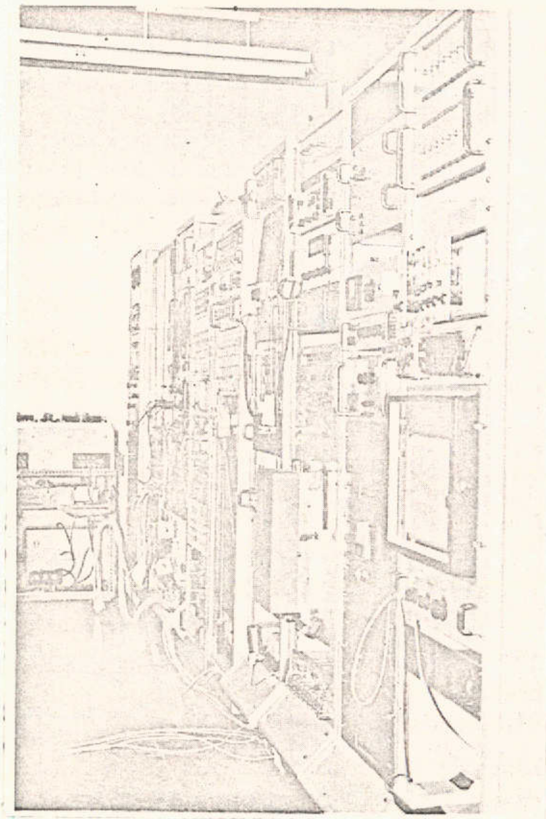


Figure 27. Instrumentation room.

in analog form. The remaining 12 parameters are practically stationary on the measurement point acquisition time scale, and are recorded in sequence about every 1.5 seconds.

The acquisition time for a test point measurement, which at the present time is about 5.5 seconds,* is organized according to the following chronological diagram (see page 39).

This operation sequence is as follows:

— recording of the point number and propeller rotation rate.

— sequential recording of twelve quasi-stationary parameters. After a time (about 1.5 seconds), corresponding to the delay introduced into the acquisition of the ten rapidly changing quantities because of the filters, simultaneous memorizing of them. Then, recording on punched tape of these ten quantities. It is necessary to record these ten filtered quantities 1.5 seconds

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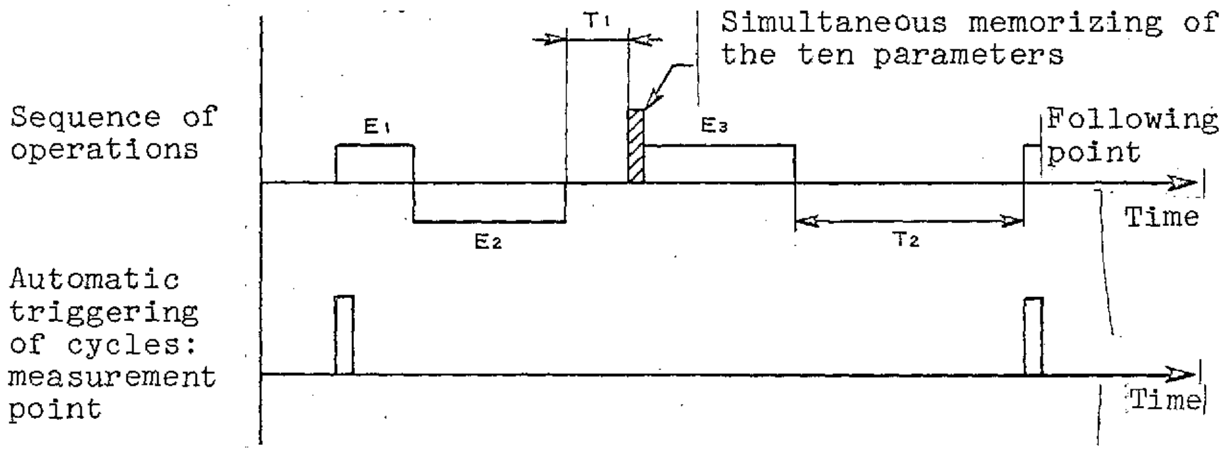
*This acquisition time of the measurement point must not be confused with the average duration of a measurement point, calculated over one test. In effect, the average duration calculated in this way integrates over periods over which no measurement points are taken (starting and stopping of the wind tunnel, starting and stopping of the motor group, variation of the "wind tunnel" and "propeller" parameters, stabilization time).



Recording:

E_1 — point number, propeller rotation period,

E_2 — recording (punched tape) of twelve quasi-stationary parameters,

E_3 — recording (punched tape) with ten changing parameters.

Waiting time:

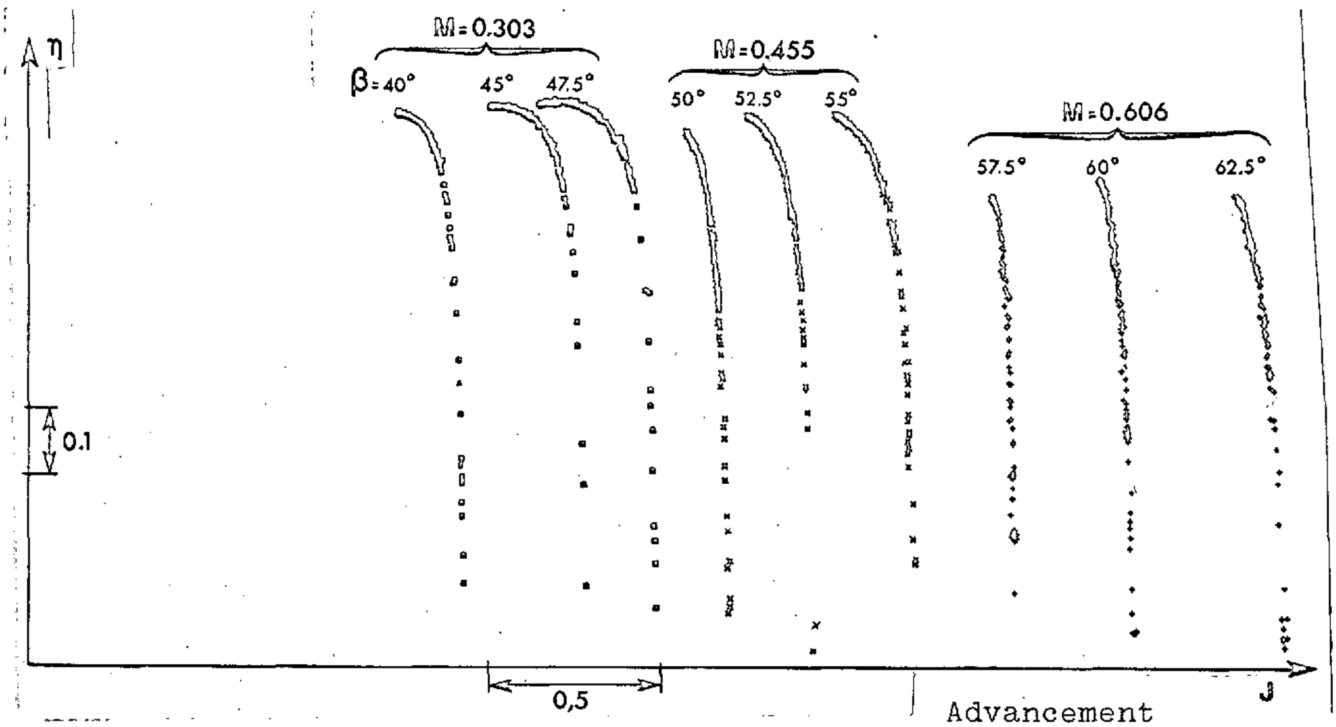
T_1 — acquisition delay (1.5 seconds approximately),

T_2 — memory recovery time and resetting to zero of the acquisition unit.

after taking instantaneous rotation rate information of the propeller, in order to provide time correspondence of the rapidly changing information. After this, there is a variable length /23
waiting time before the next measurement point, so as to be able to reset the acquisition unit to zero. The selection of the rate of measurement points automatically provides for triggering of this sequence.

It would not be necessary to determine the information simultaneously if the test conditions were stable during the recording of the measurement point. However, this stability sometimes takes long to achieve. With this method, it is not necessary to wait for perfect stability. This technique has the particular advantage of carrying out measurements while

Efficiency



Advancement parameter

Figure 28. Measurements carried out with continuous variation of the propeller rotation rate. Analyzed results, automatically plotted by points on a tracing table (without smoothing).

letting one of the test parameters vary in a continuous way.

For example, during the "B" tests (see Chapter V.2) of convertible propellers, a certain number of measurement points were recorded while there was a continuous variation of the propeller rotation rate. The propeller pitch and the wind tunnel velocity were maintained constant (Figure 28). Under the condition that the acceleration due to propeller rotation is sufficiently small so that the inertial forces and moments are negligible, we were able to verify that the results obtained with this method were of the same quality as those obtained under stable conditions.

The advantage of this method is to reduce the test time and provide more information. This is done provided that the aerodynamic coefficients at the wind tunnel velocities and the constant propeller pitch are very well defined.

IV.2.3. Measurement Accuracy

The maximum absolute error for the various measured quantities is given in the following table:

Parameters	Absolute error	Units
Static pressure (counterpressure plus capsule)	±4	daPa
Generating pressure	±2	daPa
Sleeve pressure (counterpressure plus capsule)	±4	daPa
Difference between venturi pressure — generating pressure	±2	daPa
Temperatures (generating and balance temperature)	±0.2	° C
Propeller pitch "standard" hub "designer" hub	 ±0.05 ±0.1	 degrees degrees
Incidence of propeller axis	±0.1	degrees
Propeller rotation rate	±1	rpm
Imbalance sensitivity threshold of the strain gauge points of propeller balance No. 4.	$\pm 2 \cdot 10^{-6}$	$(\Delta R/R)$

/24

IV.3. Monitoring and Measurement of Dynamic Stresses

IV.3.1. Monitoring and Test Execution (see Figure 6, page 6)

The conduction and monitoring of the tests are essentially divided into three test stations connected by intercoms:

— The wind tunnel control room (called "fixed room" because it is independent of the mobile test wagons) remotely controls the turbines which drive the wind tunnel blowers. The operator has all the information regarding the operation of the turbines and the flow conditions in the test section (wind tunnel references).

— The test room where an operator controls the operation of the motor group and the propeller, depending on a previously established test program. Besides indications regarding the operation of the motor group, this operator follows the rotation rate on a screen indicator (in rotations per minute). He also observes the propeller pitch and commands their variations.

The same room contains the test director desk, from which the test sequence is commanded.

— The measurement room which holds the acquisition equipment for the various measurements. The operator has a digital voltmeter with which he can verify and select all the measured quantities during the test, which are then subsequently recorded on punched tape.

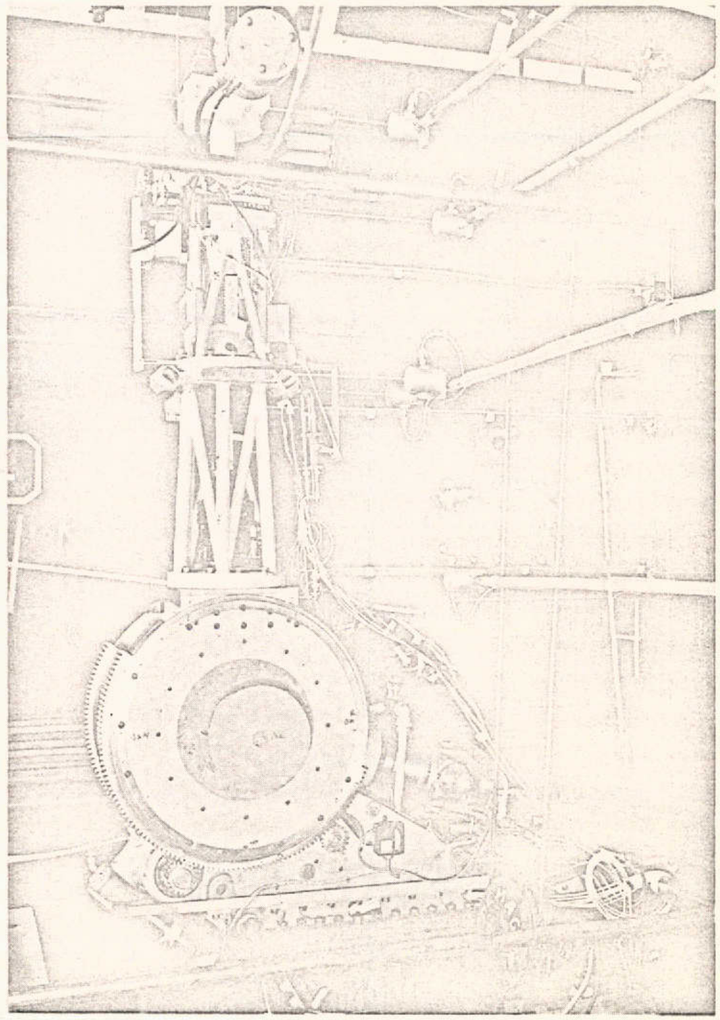


Figure 29. Study of the dynamic behavior of the test stand for helicopters and convertible propellers.

IV.3.2. Monitoring of Dynamic Stresses

In order to avoid diverging instability phenomena which could result in the failure of one of the test units, there is continuous monitoring over the entire test period.

Dangerous instabilities can occur in the propeller, or in the test stand, and these can be produced by the various energy sources: wind tunnel and motor group. The test /25 installations are subjected to dynamic tests outside of the wind tunnel with which their own dynamic characteristics are determined (Figure 29). Also, their behavior in the wind tunnel has been observed during previous tests.

One unknown which still remains (a total or partial unknown, depending on the information which the designer has) is the propeller being tested, with the possible couplings between it and the test installation. It is this uncertainty which makes it necessary to continuously monitor the equipment during the tests. This monitoring essentially consists of observing strain gauge signals located on the propeller blade and the signals from the seven balance bridges.

In addition, it could be interesting to observe the signal of the strain gauges located on the guide wires and of accelerometers located at certain sensitive locations within the installation. All of these electrical signals are displayed on two megascopes which are monitored by one or both operators. The screens of these two devices can be photographed (Figure 30). All of the signals are recorded on magnetic tape. In case it is necessary to have the spectrum of the dynamic component of any of these signals, this can be done immediately by using a spectral analyzer.

The alarm signal is available to the operator and alerts the test director. He immediately takes emergency measures to stop the danger. In particular, if divergent instability phenomena develop, the emergency measure consists of immediately turning off the wind tunnel, and this can be done very quickly.

Monitoring. Signal visualization (point No. 2343. Propeller rotation rate N_H = 1070 rpm).

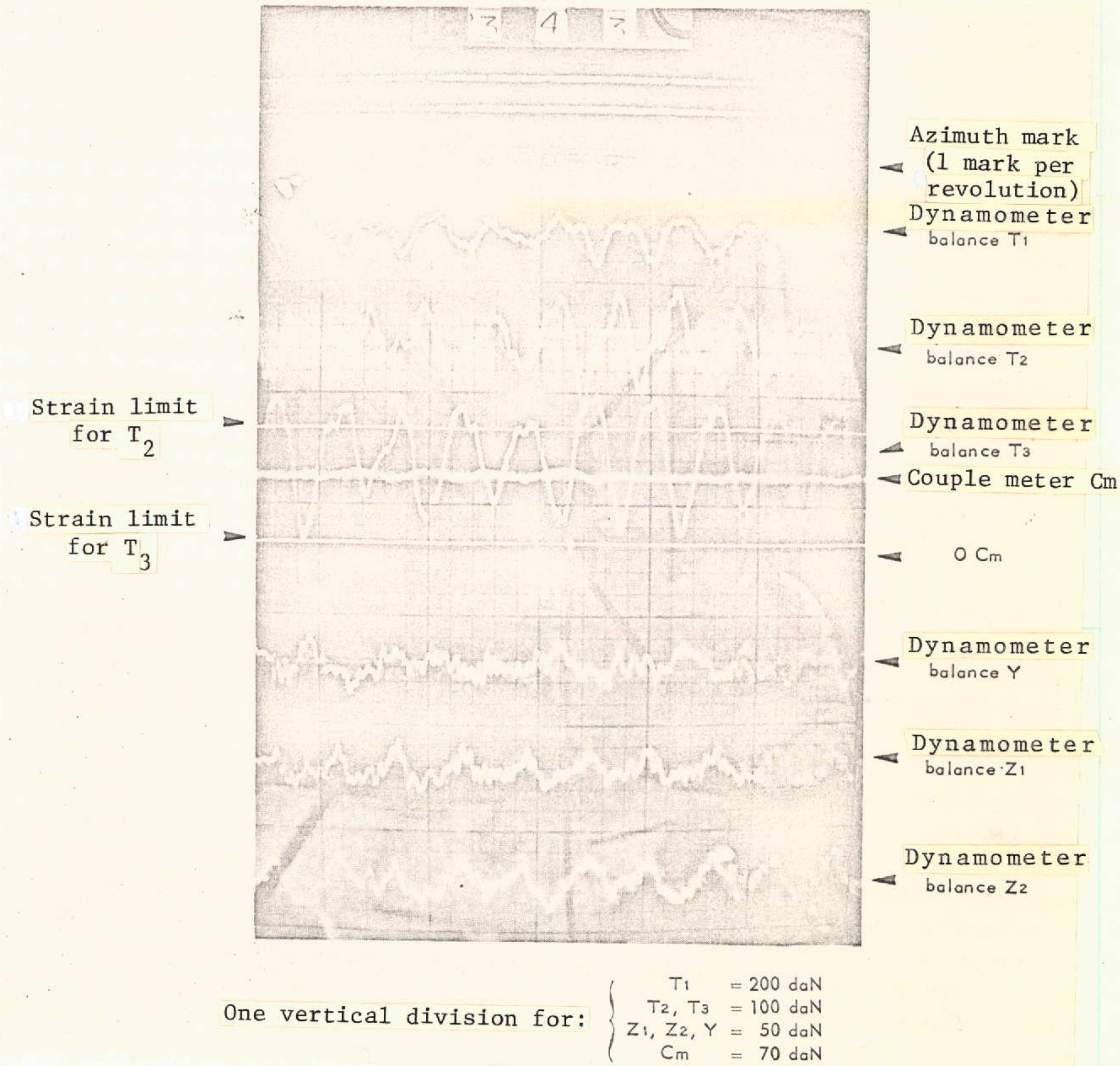
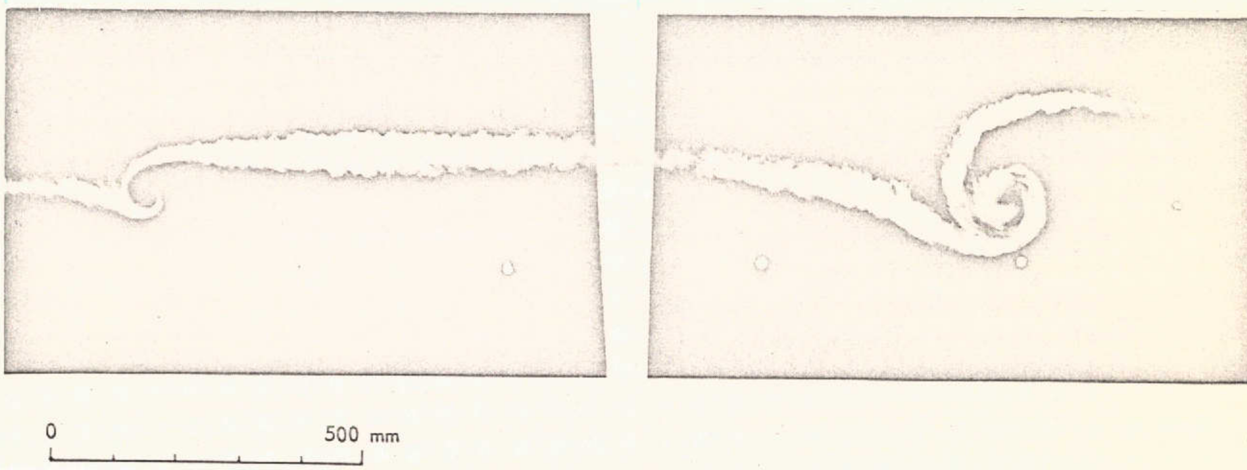


Figure 30. Photograph of a megascope screen during a high velocity propeller test (Mach 0.77).

IV.3.3. Measurement of the Dynamic Stresses on the Propeller

The recording of the electrical signals of the strain gauge bridges located on the blade, which is usually done for dynamic



Vortex scale

$M = 0{,}227$ $\alpha_H = 30°$ $\gamma_H = 1{,}08$ $T_H = 363$ daN $C_{int.} = 279$ m.daN

Figure 31. Visualization of edge vortices by smoke created with a four-meter diameter propeller.

monitoring of the blades, is also sometimes the aim of the test, or constitutes a partial result of the test. The principle and technique of the test are therefore the same as discussed in the preceding paragraph.

IV.4. Additional Investigation Possibilities

Because of the wind tunnel installations, there are numerous and diverse possibilities of additional investigations. Here we will discuss those which are related to the use of the stroboscopic installation in the wind tunnel.

The observation of a rotating blade which is stopped optically makes it possible to measure its deformations. This is done by photographing reference points painted on its surface. It is also possible to study the transition of the surface boundary layer of the blade using a sublimable coating. Finally, by installing smoke upstream of the propeller, it is possible to /27 observe and photograph the edge vortices produced by the propeller rotation using stroboscopic illumination (Figure 31).

IV.5. Analysis and Presentation of the Results

The information recorded on the punched tape is transmitted by teletype and is analyzed during the test by the central computer. It provides analyzed results and can transmit them to the measurement room using the same channel, These results can be presented in various forms:

— graphical representation: $C_T = f(J)$ $C_p = f(J)$ $\eta = f(J)$ curves (parameters: β propeller pitch, and M: wind tunnel Mach number); which makes it possible to rapidly evaluate the measurement quality during the test;

— tabulated state;

— magnetic recording tapes.

These results include:

— the wind tunnel reference quantities, where the wind tunnel velocity is corrected for wall effects according to the method developed by Glauert [7], modified [8] to take into account compressibility effects;

— various forces measured on the propeller: total force and forces corrected for the presence of the point forebody;

— aerodynamic coefficients (helicopter or propeller type) including the coefficients of force, power, lift, pitch moment, etc., as well as efficiency.

These aerodynamic coefficients are provided along the axis connected with the wind (Eiffel) or connected with the propeller axis (Lilienthal).

The maximum relative errors for these various quantities are given in [9]. The essential ones are given in the following table:

| Parameters | Symbol | Relative Errors | | /28
|---|---|---|---|
| | | M = 0.3 | M = 0.7 |
| Wind tunnel Mach number | $\Delta M/M$ | 0.0047 | 0.0012 |
| Wind tunnel velocity (not corrected for wall effects) | $\Delta V/V$ | 0.0055 | 0.0019 |
| Advancement parameter | $\frac{\Delta J}{J}$ | 0.0059*
0.0063** | 0.0023*
0.0027** |
| Force coefficient | $\Delta C_T/C_T$*** | 0.0138*
0.0223** | 0.0135*
0.0218** |
| Power coefficient | $\Delta C_P/C_P$ | 0.0047*
0.0046** | 0.0037*
0.0043** |
| Propeller efficiency | $\Delta\eta/\eta$ | 0.0184*
0.0256** | 0.0135*
0.0213** |

*Two meter diameter propeller rotating at 2200 rpm

**Four meter diameter propeller rotating at 1200 rpm

***The maximum relative error in all of the other aerodynamic coefficients is their order of magnitude.

V. RECENT RESULTS /29

In order to illustrate the possibilities and performance of the installation, we will now mention certain results from three recent test series, within the constraints of industrial security.

V.1. "A" Propeller Tests

This test series was carried out using six large-scale propellers (scale close to or equal to 1). It was carried out on the "minimum body" installation. The purpose of these tests was to validate the two methods of determining the characteristics of a propeller: calculation method and wind tunnel test methods.

The propellers tested during these tests are the following:

— the 1/1.8 scale model of a three-blade STOL aircraft propeller;

— a four-blade propeller for a bi-turbojet business aircraft;

— a four-blade propeller for a quadri-turbojet aircraft;

— two propellers used in a bi-turbojet transport aircraft (one was studied in particular for improving the high altitude performance);

— a propeller for a medium power turbojet.

This sampling was selected so as to give an idea of the usual propeller load range ($0.01 \leq C_P \leq 0.24$). Of these propellers, some of them were calculated using the theoretical method developed by a French aerospace designer. The others were evaluated using a semi-empirical method of a propeller designer.

For each of these propellers, three points corresponding in general to the conditions of takeoff, ascent, cruise were verified in the wind tunnel. The tests were carried out so that in the wind tunnel nine test points were covered with a constant blade tip Mach number, which included the calculation point in their range.

The comparison of the test results and the theoretical calculation results was done by the author of the method for two propellers. These comparisons show complete agreement between the calculation and the test results. (See table, page 51.)

These tests led to the measurement of the drag of point forebodies of "standard ONERA" hubs with three and four blades, which constitute standard propeller test stand equipment. /30

The velocity field induced in the propeller plane by the two point forebodies was measured using a rake of the same type, but it was shorter (320 mm) than the one used at present (Figure 32).

V.2. "B" Convertible Propeller Tests

The definition of a convertible propeller project led to several test programs for defining the propeller performance up to a cruise Mach number of 0.70 with zero incidence and for transition flight up to a propeller axis incidence angle of 95°.

The propellers tested were calculated by an American company and they were manufactured by a French company.

The convertible aircraft is a four-motor cargo aircraft with turning wings equipped with four propellers seven meters in diameter.

The models of these propellers studied at Modane are two meters in diameter (scale 1/3.5). They differ in terms of twist and profile distribution along the blade. They were first tested at zero incidence during two first test sequences (Figure 33).

	Flight regime	Propeller operating conditions			Calculation(1)						S1MA Test		
					Ideal surface state			NACA test surface state					
		J (2)	C_p	M_p	β	C_T	η	β	C_T	η	β	C_T	η
Second propeller	Takeoff	0,57	0,221	0,72				27°,4	0,235	0,606	29°	0,233	0,601
	Ascent	0,871	0,224	0,73				31°	0,192	0,746	31°	0,194	0,755
	Cruise	1,746	0,228	0,84	40°	0,114	0,875	40°	0,113	0,865	42°	0,1125	0,860
First propeller	Takeoff	0,31	0,043	0,84				15°,5	0,084	0,605	15°,3	0,0835	0,601
	Cruise	1,48	0,073	0,84				35°	0,0417	0,849	34°,5	0,0418	0,850

(1) Two surface states were considered in certain calculations:

— an ideal state corresponding to a roughness of less than 0.5 microns.

— a state with small roughness, corresponding to tests published in the NACA documentation (on the order of 2 microns).

(2) J — advancement parameter

C_P — power coefficient

M_P — blade tip Mach number

β — pitch of blades (measured over the profile of the blade at 70% radius)

C_T — force coefficient of propeller alone

η — efficiency of propeller.

All these quantities are calculated using conventional propeller conventions.

[Translator's Note: Commas in the numbers indicate decimal points.]

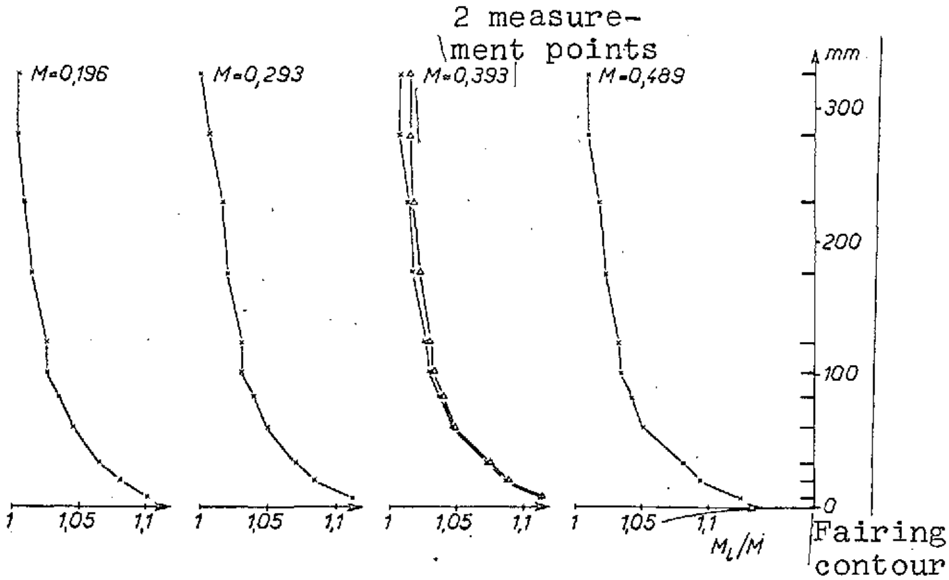


Figure 32. Velocity field in the propeller plane (three- and four-blade point forebodies).

Their rotation rate varies between 1000 and 2350 rpm, and the pitch at 75% radius is between -9 and 62°. The Reynolds number calculated for the profile at 75% radius is between 1 and $2.6 \cdot 10^6$. During these tests, we first determined the influence of the environment on the propeller performance while fixed, by testing the propeller in the presence of walls which simulated the ground and the aircraft fuselage (Figure 34).

The subsequent test series repeated the previous experiments under the various configurations and determined the data with a greater degree of accuracy. The propeller characteristics during transition flight were determined, and its normal environment was partially simulated.

In this way, we were able to show the fidelity of measurements made one year apart during the two test series (Figure 35). Also, we established the influence of the shape of the propeller base on the propeller performance when the propeller was rotating

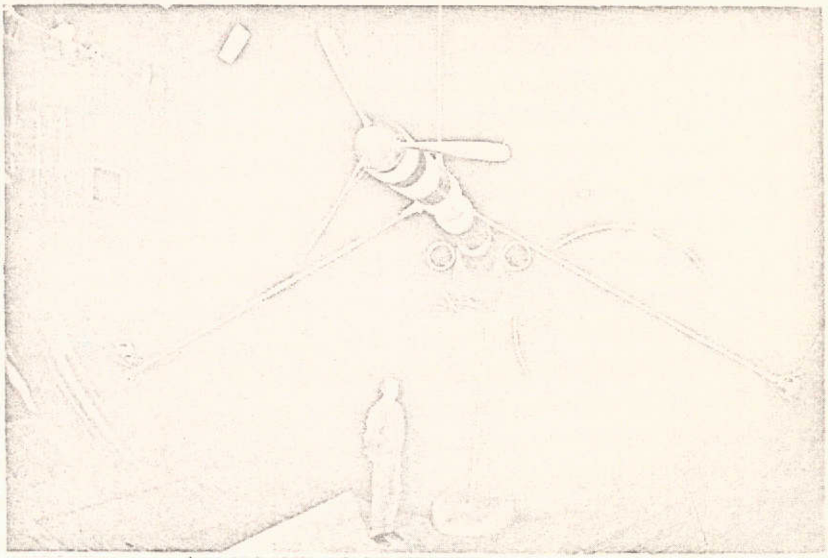


Figure 33. Convertible propeller in the test section on the "minimum body" installation.

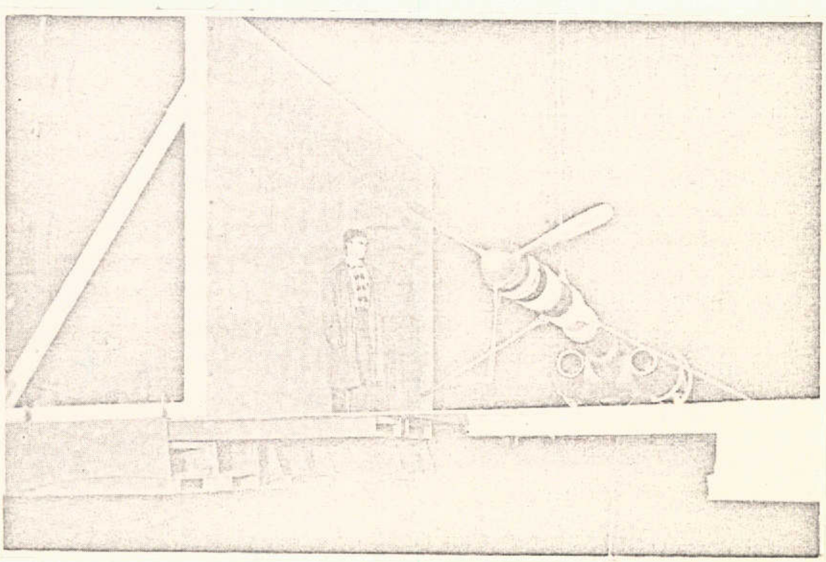


Figure 34. Influence of the surroundings on the performance of a fixed propeller.

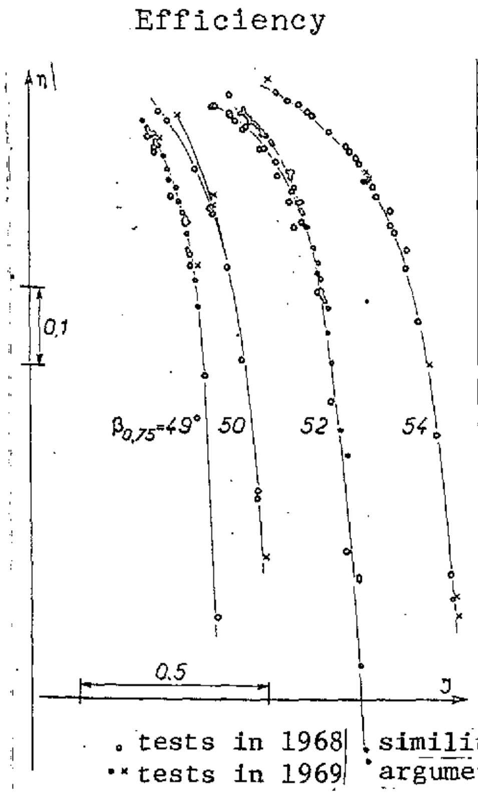


Figure 35.

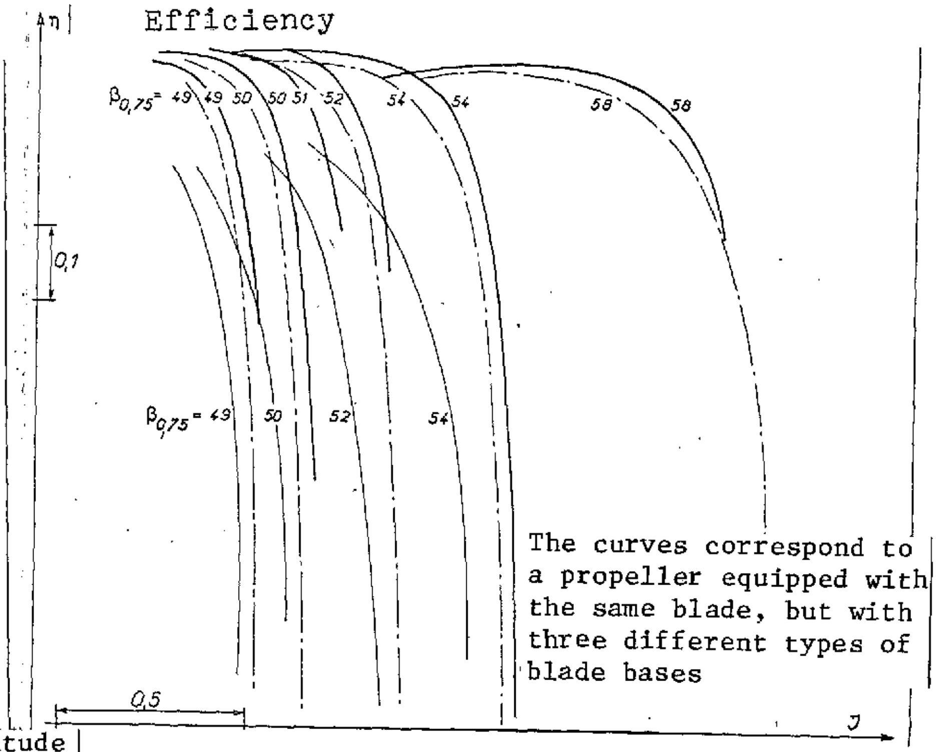


Figure 36.

at a high velocity (Figure 36). This explains the deviations between the wind tunnel test results and the calculation results found during the first test series.

The tests with the propeller alone in the transition flight configuration ($0° < i \leq 95°$), and the test of the propeller operating in the wake of a wing (Figure 37) and while operating upstream of the wing (Figures 38 and 39) led to an estimation of the influence of these conditions on the six aerodynamic components of the propeller.

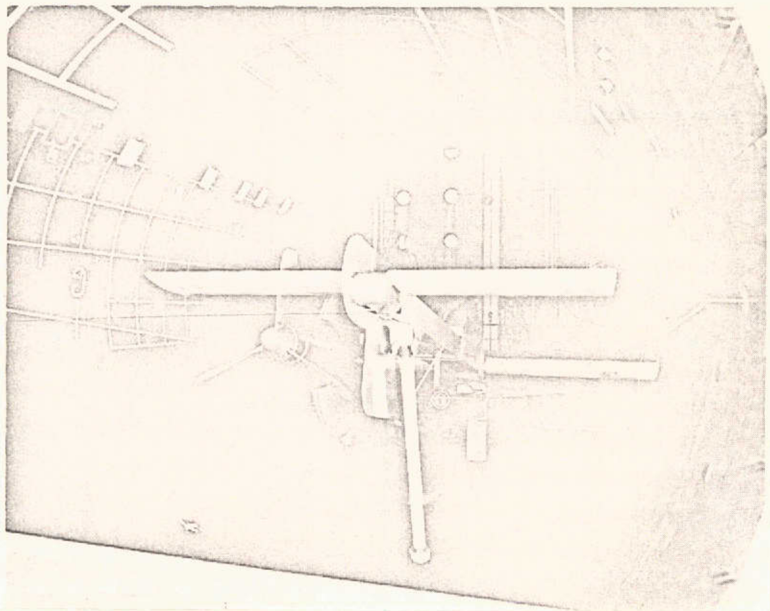


Figure 37. Convertible propeller in the wake of a wing at i ~ 30°

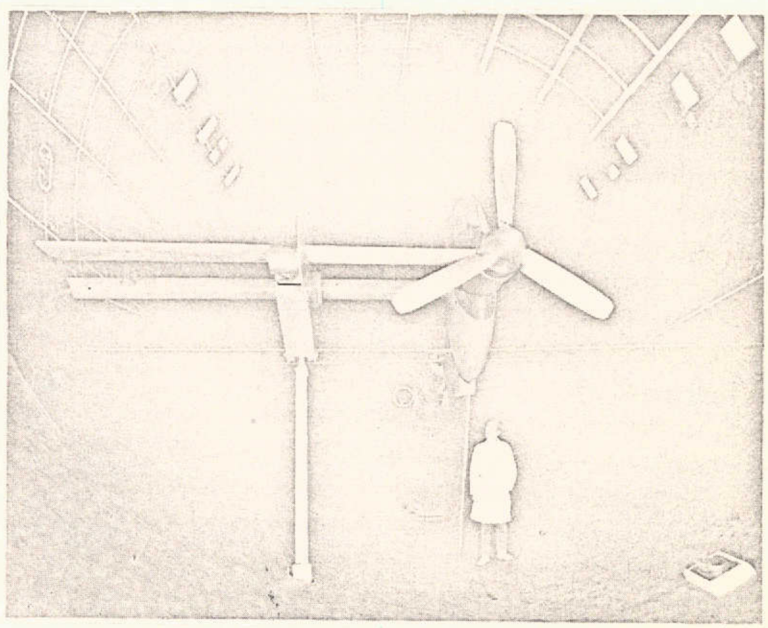


Figure 38. Convertible propeller operating upstream from a wing — i = 0°.

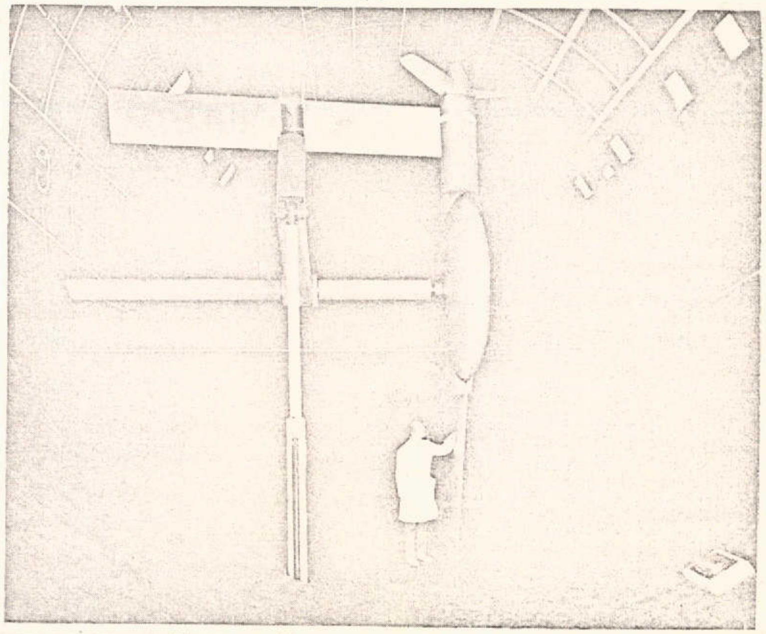


Figure 39. Convertible propeller operating upstream of a wing $i \sim 90°$.

V.3. "C" Convertible Propeller Test

The convertible "C" propeller project with adjustable blades /33 was done using two propellers 55 feet in diameter (approximately 17 meters). The study of the performance of these high velocity propellers was carried out by the S1MA using two models at a scale of 13/55 (approximately 1/4).

This study was continued in a joint program established between NASA (National Advisory and Space Administration) and the ONERA (Office National d'Etudes et de Recherches Aerospatiales) on joint research on convertible rotors. This agreement included the exchange of information, tests with various models in American wind tunnels (Wright-Field-Ames wind tunnel of the U. S. Army — 7 x 10 feet and the large 40 x 80 foot wind tunnel) as well as tests at the S1MA. In the S1MA, tests were only carried out in the velocity and dimension range which were possible in this wind tunnel. For these tests, the propeller models and the hubs were furnished by the designer. The adaptation of this equipment to the S1MA test stands was provided by the ONERA.

The tests determined various parameters (deformations, propeller stresses, etc.), as well as the influence of the twist of the blades on the propeller performance rotating at a large velocity. These results were compared with the calculations.

During the first test series (1968 and 1969), five propeller models were tested having identical profile distribution but different twists.

One of the tested propellers was tested in the transition flight configuration ($0 < i < 115°$). Finally, in 1970, we tested a propeller model selected for the aircraft, and the twist selected for the aircraft. This model was dynamically similar to the real propeller because of the particular blade structure. The results obtained in the various American wind tunnels and the S1MA with 13/55 scale models (Modane and Ames wind tunnel 40 x 80 feet) and the 1/11 scale models (Ames U.S. Army wind tunnel 7 x 10 feet and Wright Field) were merged together with the calculations. From this, predictions of the convertible propeller with adjustable blades were made as accurately as possible.

VI. CONCLUSION

The equipment available for testing propellers at the S1MA wind tunnel at Modane-Averieux offers designers a very wide range of test conditions: propeller diameters up to 4 meters, incidence angle ranges during tests from $-5°$ to $115°$; available /34 power 1100 kW; maximum rotation rate 2400 rpm; many possible configurations (minimal cylindrical body, motor cowling, representation of cell elements near propeller, drive by real turbomotor); measurement of the six components of aerodynamic force for propeller alone or with motor cowling, partial weighing (point forebody), pressure measurement, stresses, deformations; flow visualization; dynamic behavior study; aerodynamic noise measurement; etc.

This equipment makes it possible to carry out very complete tests, tests of quasi-steady flight up to maximum velocity with all desired configurations at Reynolds numbers close to flight values for both classical aircraft propellers or convertible propellers with adjustable blades.

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